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1998 Army After Next Unmanned Aerial Vehicle Studies

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There has been growing recognition within the senior leadership of the Army that UAVs are an emerging technology which may play a critical role in the Army After Next. The CSA directed Army After Next (AAN) effort to frame issues vital to the development of the US Army after about 2025 and to provide those issues to senior Army leadership in a format suitable to integration into TRADOC Combat Development programs. The Army After Next Directorate and the Director of TRAC Leavenworth initially requested USMA to analyze a proposed notional UAV force structure and provide recommendations and alternatives. To date, USMA has been involved with the Tactical Wargames, conferences, In Progress Reviews, has conducted some initial modeling which has resulted in a UAV requirements analysis focused on the Battle Element, and has presented a final briefing to the Directors of the AAN, TRAC Leavenworth, and the Battle Lab Integration Technology and Concepts Directorates. Some potential key insights concerning the contribution of future Unmanned Aerial Vehicles (UAVs) systems have been brought to light.

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Executive Summary

There has been growing recognition within the senior leadership of the Army that UAVs are an emerging technology which may play a critical role in the Army After Next. The CSA directed Army After Next (AAN) effort to frame issues vital to the development of the US Army after about 2025 and to provide those issues to senior Army leadership in a format suitable for integration into TRADOC Combat Development programs. The Army After Next Directorate and the Director of TRAC Leavenworth initially requested USMA to analyze a proposed notional UAV force structure and provide recommendations and alternatives. To date, USMA has been involved with the Tactical Wargames, conferences, In Progress Reviews, has conducted some initial modeling which has resulted in a UAV requirements analysis focused on the Battle Element, and has presented a final briefing to the Directors of the AAN, TRAC Leavenworth, and the Battle Lab Integration Technology and Concepts Directorates. Some potential key insights concerning the contribution of future Unmanned Aerial Vehicles (UAVs) systems have been brought to light.

Our mission and requirements analysis, requirements survey, and subsequent functional decomposition, uncovered the following potential critical UAV missions: reconnaissance, tracking and surveillance, electronic warfare, identification of friend or foe, target acquisition and designation (down to the individual vehicle), battle damage assessment, and communication processing. Additionally, we found these other critical UAV missions: confirming data from other sensors; enhancing unit security; supporting urban warfare; performing NBC detection, and operating in all weather conditions.

Some important modeling considerations were data validation and subsequent scenario validation and verification. If the simulation models are to produce credible results, the data and scenarios must be accurate and reflect evolving AAN doctrine. EADSIM proved to be a very capable, useful modeling tool, but it is also extremely complex. Quick generation and analysis of scenario, is not advisable. Post-game analysis should be conducted to investigate why things turned out the way they did. The variance of the outcomes from our simulation trials was high, which implies many iterations must be run to draw conclusions with any level of statistical certainty. From the evolving requirements for the organic BE UAV's, we found the following interesting time, space, and altitude relationships: UAV speeds will more than likely have to be at least four times that of the Advance Fighting Vehicles' ground speed; the Deadly Zone distances may need to be much larger; and the number of target the BE must engage may be between 100 to 200. The findings from our study suggest four potential areas for further investigation: UAV speed, altitude, range, and the number of target acquisition and designation requirements. These are certainly not the only four areas, but are areas which came to light as a result of our investigations.

We found a UAV centric attitude towards identifying and defining UAV requirements and force structures. We took a boarder approach and feel more consideration should be given to the super and lateral system interface requirements and to the integration of the information and knowledge before more force structure analysis continues. The living

Internet and the Intelligence Surveillance Reconnaissance (ISR) structure will undoubtedly play an integral part in the support of the UAV structure.

We fell future research should continue in the areas of requirements analysis for all Battle Force echelons (Force, Unit, and Element), super and lateral system interfaces, and integration of all systems. Continued investigations into the modeling simulation, and prototyping of UAVs and of the AAN C4ISR infrastructure should also be pursued. Perfect, real time, and instantaneous information is not a luxury we should assume and base our further investigations on.

1 Introduction

1.1 Problem Background

The purpose of the CSA directed Army After Next (AAN) effort is to frame issues vital to the development of the US Army after about 2025 and to provide those issues to senior Army leadership in a format suitable for integration into TRADOC Combat Development programs. There has been recognition within the senior leadership of the Army that UAVs are an emerging technology which may play a critical role in the Army After Next. An AAN Working Group (the Director of the AAN directorate and the Director of TRAC Leavenworth) requested USMA's involvement to assist in the investigating the roles of UAVs. The initial requirement was to analyze a proposed notional UAV force structure and provide recommendations and alternatives.

To date, two USMA Cadet and Faculty teams have attended several Tactical Wargames, conferences, In Progress Reviews, conducted some initial modeling which have resulted in an initial UAV requirements analysis, focused on the Battle Element, and has presented a final briefing to the Directors of the AAN, TRAC Leavenworth, and the Battle Lab Integration Technology and Concepts Directorates. To assist in the modeling and simulation and the requirements definition efforts, it was necessary to recreate some of the wargames AAN systems in constructive and virtual simulation environments. This helped us to understand their relative contribution to future concepts of operation in both quantitative and qualitative terms. Key insights were discovered concerning the contribution of future systems such as the suite of Unmanned Aerial Vehicles (UAVs) to traditional lethality measures of effectiveness and also to new measures of information gain, such as the Common Relative picture, improved Situational Awareness, and new measures of non-linear mobility. The relationships among mobility, information, and lethality may be of particular interest and how UAVs integrate with ground systems, the living Internet, the Intelligence Surveillance Reconnaissance (ISR) structure, and national reconnaissance assets. Critical research questions continue to be:

* What are the AAN commander's information requirements?

* What are the UAV system requirements?

* What is the UAV structure is necessary to support an AAN battle force?

1.2 Analytic Framework

To assist in our analysis of this problem, we used an analytic framework called the Systems Engineering Design Process (SEDP). Figure 1 presents a graphical representation of steps involved in the SEDP.

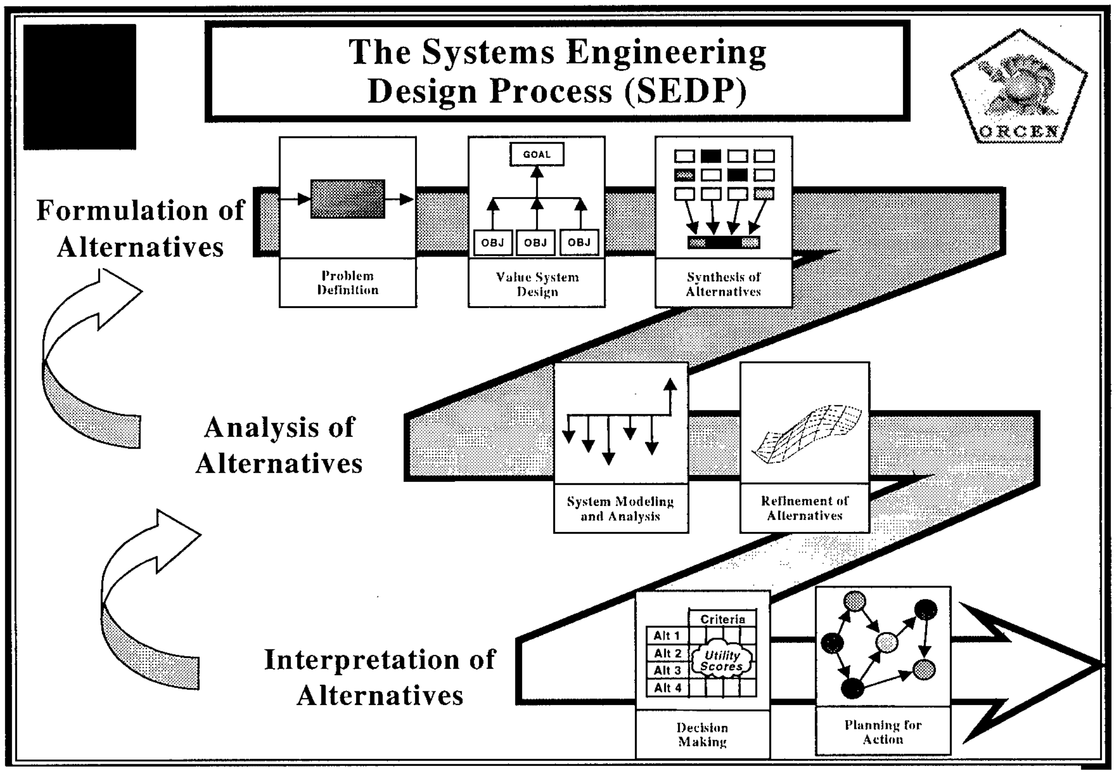

Figure 1: SEDP

This process breaks the problem down into a series of steps which guide the analytic effort. These steps build on one another, each helping further define and subsequently find potential solutions to the problem. As the feedback loops indicate, the SEDP is iterative in nature; the process is not complete until a decision is made and implemented.

1.3 Study Methodology

The Systems Engineering Department at the U.S. Military Academy teaches cadets how to deal with large, ill-defined, interdisciplinary problems. These Army After Next UAV studies have provided just the sort of problem that we like the cadets to wrestle with. Our intent has been to:

- Provide a rigorous capstone design experience to a team of senior level Systems Engineering cadets by having them work on a difficult real-world problem with actual Army clients.
- Provide a professional development opportunity to Systems Engineering faculty.
- Help the Army After Next community understand the implications of proposed UAV requirements, alternatives, and architectures.
- Provide Army After Next analysts with an independent set of eyes to suggest blind spots in the discovery process.
- Where appropriate, assist in the modeling and analysis of future UAV systems, particularly UAVs.

Our work this year focused on two particular areas within the SEDP design process. We had one team focus on the formulation of alternatives, characterizing potential UAV requirements and structuring the criteria that could be used to evaluate how well various UAV alternatives meet those requirements. The second team looked at alternative UAV modeling environments, investigating the roles that advanced virtual prototyping tools and distributed interactive simulations could play in the evaluation of potential Army After Next systems. Together, the two teams have made a great deal of progress toward defining the role of UAVs for the AAN Battle Element, and structuring a modeling environment that can be used to evaluate various aspects of UAV effectiveness. This work has been validated through some initial simulation modeling, and the results are presented in this report.

2 Requirements Analysis

2.1 Determining the Requirements

2.1.1 Initial Tasking:

The Director of the Future Battle Directorate, Deputy Chief of Staff for Doctrine (DCSDOC), US Army Training and Doctrine Command (TRADOC) in conjunction with the Director of TRADOC Analysis Command (TRAC) Ft Leavenworth requested the Department of Systems Engineering at the United States Military Academy (USMA) evaluate the Army After Next (AAN) Unmanned Aerial Vehicle (UAV) strawman force structure, investigate feasible force structure alternatives, and optimize the recommended AAN UAV force structure.

2.1.2 Problem Definition:

One of the first steps in our analysis was to identify the key stakeholders and cinduct a stakeholders' analysis to identify their critical requirements (a needs analysis). This was accomplished through participation in AAN tactical Wargames, numerous conferences, In Progress Reviews, research, and a survey of senior AAN personnel (see appendix TBD for AAN UAV Study Activities). Our initial finding were that there were many viewpoints, multiple competing objectives, and no established consensus on UAV evaluation criteria. The impact on our study was that the evaluation of the proposed AAN UAV strawman was impossible without established evaluation criteria. Our study focus shifted and became centered on identifying the AAN UAV requirements and defining evaluation criteria. Our restated mission (Effective Need Statement) is discussed below in paragraph 2.1.3. Some of the key stakeholders are:

* COL Gay: Director Future Battle Directorate, DCSDOC TRADOC

* COL Kirin: Director TRAC Ft Leavenworth

* COL McHaffey: Director, Battle Lab Integration Technology and Concepts Directorate, DCSDOC TRADOC

* BG (ret) Huba Wass de Czege: Advisor to CG TRADOC

* LTC Franke: Technologist, Future Battle Directorate, DCSDOC TRADOC

* LTC Cronin: Future Battle Directorate, DCSDOC TRADOC

* MAJ Jake Biever: Action Officer Future Battle Directorate, DCSDOC TRADOC

* MAJ Brian DeMeyere: Action Officer Future Battle Directorate, DCSDOC TRADOC

2.1.3 Restated mission: Conduct a Requirements Analysis

A critical part of our research became the understanding of the AAN strategic, operational, and tactical concepts and the resultant information requirements of the AAN commander so evaluation criteria could be defined. We found that the strategic and operational concept behind the AAN Battle Force is the Strategic/Operational Ambush

("Coup de main").[1] We also found from the AAN wargames that superior knowledge or "Knowledge Dominance" on the battlefield increased, by orders of magnitude, speed of maneuver, which allowed for the employment of the ambush dynamic.[2] This conceptual understanding enabled the investigation and identification of critical UAV missions and the subsequent functionally decomposition into required system capabilities. The size and complexity of the Battle Force echelons forced us to bounded the study. The focus of the study was on supporting the Battle Element attack and the reviewing potential UAV modeling approaches.

2.2 Key UAV Requirements and Functions

2.2.1 Operational Scenario

In figure 2 below, the Decisive phase of the strategic/operational ambush begins as the Battle Element (BE) is inserted.

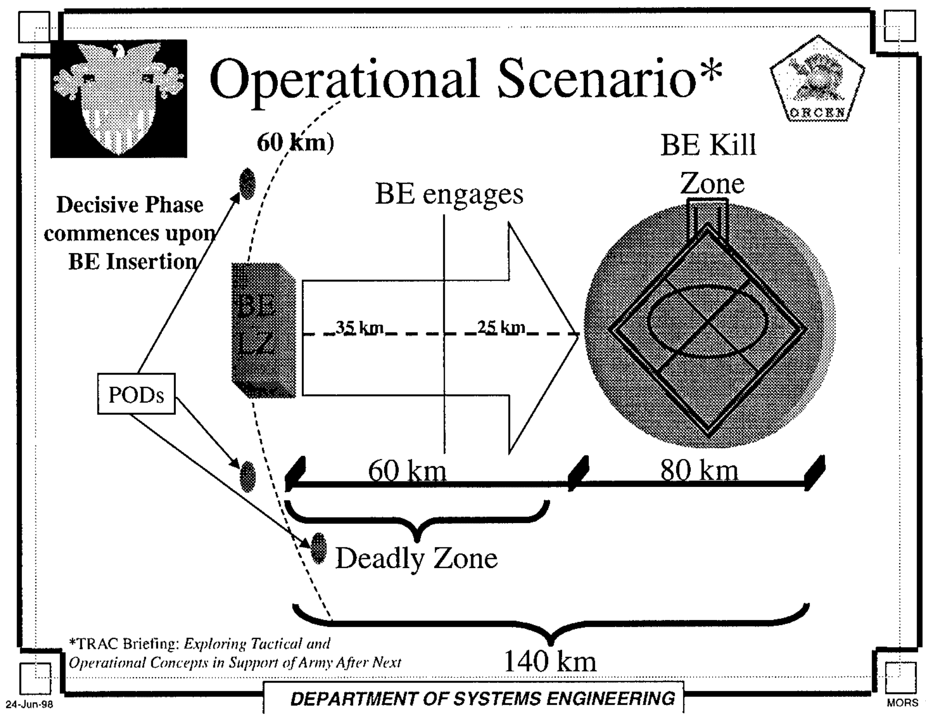

Figure 2: Operational Scenario

The Decisive phase commences, as the indirect fire pods (pre-positioned approximately 60 Km way from the BE kill zone) and reach back assets provide suppressive and covering fires for the insertion of the BE. The Decisive phase lasts approximately 30 - 60 minutes. The Battle Force (BF), Battle Unit (BU) UAVs, satellites, and or other

[1] Knowledge and Speed: The Annual Report on The Army After Next Project to the Chief of Staff of the Army Knowledge and Speed, JUL 97, pg 20
[2] Knowledge and Speed: The Annual Report on The Army After Next Project to the Chief of Staff of the Army Knowledge and Speed, JUL 97, pg 13

echelons above BF assets provide Knowledge Dominance (Common Relative Picture) and target data for the commander, the reach back assets and the firing pod assets. Upon insertion or just prior to, the BE organic UAV will deploy and speed to the BE Kill zone, providing route recon data, virtual leaders recon data, and early warning. Additionally, as the BE organic UAVs transit the entire distance (deadly zone and BE Kill Zone), they must receive an updated CRP, and target data from the non organic UAVs. The BE organic UAV must identify, designate, and prioritize targets to allow for an optimal allocation and distribution of all remaining key targets amongst the BE organic line of sight and non-line of sight firepower. This critical BE UAV activity must occur before the BE ground Advanced Fighting Vehicles travel the 35 km to their engagement point, at 25 Km. At the engagement point, the BE organic (line of sight and non-line of sight) weapons will engage and destroy the last of the remaining elements of the enemy BN task force.[3]

2.2.2 Assumptions

* Ground speed of BE AFV will remain constant: ~100 kph[4]
* BE UAVs will be carried with BE and launched immediately upon insertion[5]
* BE LZ for insertion is ~ 60-75 km from enemy
* Pods positioned ~ 60 km from enemy

* Ambush starts when BE inserts.

* Decisive phase lasts 30-60 minutes

* Deadly zone/Enemy engagement range = 40-50 km

* BE engages at ~ 25 km from Kill Zone

* Within ~0.35 hr (ground time to cover 35 km), BE must:[6]

* Receive update from CRP

* Identify all targets

* Designate all targets

* Prioritize targets

* Optimally allocate and distribute

* BE Kill Zone ~ 80 km (diameter)[7]

* Major Military Competitor[8]

* BF engages an enemy division: 1600 key targets[9]

* "Rule of Six" implies:[10]

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[3] Ibid.
[4] Made by analyst
[5] Ibid.
[6] Ibid.
[7] The Army After Next Battle Force, Army After Next Tactical Workbook, 2 JAN 97 pg 16
[8] Knowledge and Speed: The Annual Report on The Army After Next Project to the Chief of Staff of the Army Knowledge and Speed, JUL 97, pg 9
[9] IPR with COL Kirin, 23 OCT 97
[10] TRAC Briefing: Exploring Tactical and Operational Concepts in Support of Army After Next slide 22.

* BE => Enemy BN (45 Key targets)

* To annihilate enemy BN Task Force, BE key targets more likely to be at least 100-200

2.2.3 UAV Roles/Missions Survey

In order to develop an effective UAV architecture for the Army After Next, it is critical that potential missions be prioritized. There are a myriad of possible UAV missions, and we frequently detected an attitude that UAVs will be a silver bullet capable of solving many of the hard problems for the Battle Force. While UAVs can certainly make significant contributions to Battle Force effectiveness, they must be designed to optimally perform specific roles and missions. To do otherwise will result in the design of expensive, general-purpose UAVs that which can perform many functions, but can't perform any particular functions well.

To determine the most important missions, we began with our initial UAV requirements and from these developed a ranking of all potential UAV roles and missions. These rankings were subsequently validated by surveying individuals who have been active in the AAN process. A survey that displayed the initial mission rankings was given to more than 20 senior participants at the AAN tactical wargame in December, and those individuals were asked to respond to the rankings, or to suggest other potential UAV missions[11]. We received 9 responses. Highlights from this survey are[12]:

- The single most important UAV mission is: gather detailed reconnaissance, surveillance, and target acquisition data (RSTA), down to the individual vehicle level.
- Other critical UAV missions are: confirming data from other sensors; enhancing unit security; supporting urban warfare; performing NBC detection; and performing BDA.
- It is also critical that UAVs be capable of operating in all weather conditions.

2.2.4 Key UAV Missions

From the operational scenario, discussed in paragraph 2.2.1, we identified some key missions and capabilities for the organic BE UAVs. The system requirement survey helped to validate our initial UAV missions and functional decomposition and also helped identified and prioritized other potential UAV missions.

2.2.4.1 Reconnaissance

The major intelligence/information requirement will most likely focus on specific geographical areas and or on enemy units and be satisfied by gathering of discrete (potentially not real-time) information snapshots, not a continuous flow of information. The Area-Oriented capabilities will include route recon, virtual leader's recon, and security recon (in terms of early warning). The Enemy-Oriented capabilities will include Identify Friend or Foe (IFF) and Counter Recon.

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[11] Appendix A contains a copy of the survey.

[12] For complete survey results, see Appendix B.

2.2.4.2 Tracking and Surveillance

Some of the critical capabilities will most likely include IFF, target classification, and obtaining targeting data, but over a much longer period of time than target acquisition. The major intelligence/information requirement will most likely focus on specific geographical areas and or on enemy units and be satisfied by gathering of continuous information, as opposed to discrete (not real-time) information snapshots.

2.2.4.3 Electronic Warfare

A critical mission for the BE organic UAV's to enhance UAV survivability and Unit mission success will likely be to perform active jamming of communication sites and Suppression Again Enemy Air Defense (SEAD) sites.

2.2.4.4 Target Acquisition

Some of the critical capabilities of target acquisition will likely include IFF, target classification, and obtaining targeting data. The length of time of the continuous gathering of target data is main difference between target acquisition and tracking. The major intelligence/information requirement will most likely focus on specific enemy units and be satisfied by gathering of continuous information, as opposed to discrete (not real-time) information snapshots.

2.2.4.5 Target Designation

The critical capability is to provide continuous and or discrete designation of targets, in real time, for recognition and terminal guidance of the various AAN smart munitions. The focus will most likely be on designating/illuminating specific enemy units and or vehicles.

2.2.4.6 Battle Damage Assessment

Much like target acquisition and tracking, some of the critical capabilities of BDA include IFF, and target classification (in terms of type of target and status: alive, mobility kill, firepower kill, communications kill, or catastrophic kill). The length of time for continuous gathering of target data will vary. The major intelligence/information requirement will most likely focus on specific enemy units and be satisfied by gathering of continuous information, as opposed to discrete (not real-time) information snapshots, but snapshots may be a secondary or backup source of information.

2.2.4.7 Communications Processing

To serve as a robust communications source, link, and backup system, UAV will likely have on board communications which will be reliable and secure. The communications capabilities will likely function in an autonomous mode to insure no degradation no matter which communication function the UAV is providing, i.e. Data source, communications link, or a backup system.

2.2.5 System Capabilities

Some potential critical system capabilities required to accomplish the above mission are listed and discussed below.

2.2.5.1 Intelligent Navigation

The BE organic UAVs must be able to conduct route planning and execute the flight plan. This capability includes the identification, location, and avoidance of all obstacles, which includes other UAVs and other air vehicles (Airspace Deconfliction). These capabilities will most likely have to be autonomous.

2.2.5.2 Communication

To serve as a robust communications backup, the on board communications must be reliable and secure. The communications system should provide UAV System Data, Sensor Data and relay Data.

2.2.5.3 Low/no operational signature

Low or no operational signature may be an important characteristic for the survivability of UAVs. This characteristic will most likely have to be weighted against aerodynamic performance, engine power and speed, airframe size, and cost.

2.2.5.4 Aeronautics:

As with intelligent navigation capabilities, the BE organic UAVs must be possess aeronautical capabilities. These capabilities will most likely have to include autonomous capabilities to:

Take off
Fly to and from the mission area of operation
Adjust speed to suit mission requirements and or conditions
Loiter as mission requirements dictate
Land safely upon completion of the mission.

2.2.5.5 Multi-Spectral Sensors

To support the required situational awareness and common relative picture information demands, the BE organic UAV's will have to have a elaborate sensor package which might include the following type of sensors:

Electromagnetic

Motion

Auditory

NBC

In addition, the UAV will probably require an autonomous capability to use a combination of sensors and or switch from sensor to sensor to obtain the essential information.

2.2.5.6 Target Designation

This critical system capability should provide continuous and or discrete designation of targets, in real time, for recognition and terminal guidance of the various AAN smart munitions. The designation from the UAV system may not necessarily be illumination, such as laser designation, but rather some other form of designation, i.e. precise target

location updates or vibrational identification. The focus will most likely be on the UAV's ability to designate specific enemy units and or vehicles.

2.2.5.7 EW capable

To enhance the UAV's survivability and that of the piloted aircraft, the UAV's will likely have capabilities to perform active jamming of communication sites and for Suppression Again Enemy Air Defense (SEAD) sites.

2.2.5.8 Neutral commander workload

A serious consideration for the commander is the addition to his/her workload. In all the system capabilities mentioned above, all will most likely have to be workload neutral to the commander and may require the full range of control from autonomous control to manual over ride control.

2.2.6 Super System Interfaces

In Figure 3 below, some of the notional super system interfaces are depicted and discussed.

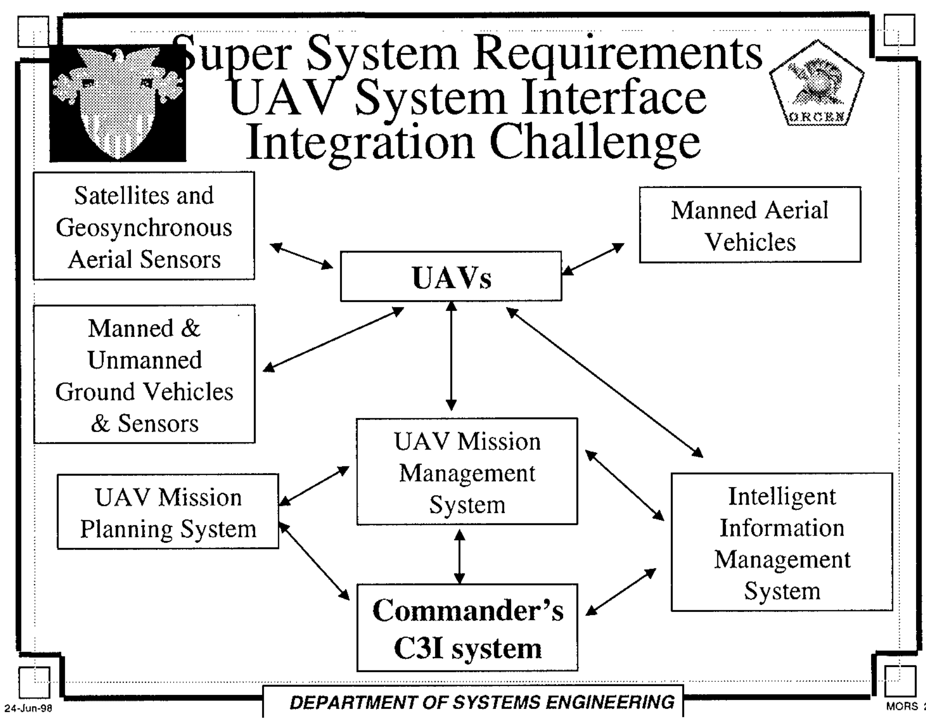

Figure 3: Super System Requirements

A notional UAV Mission Planning System might require the following inputs and outputs:

Inputs:

CDR's requirements
Time Constraints

Mission
Desired Information Quality
Rules of Engagement
Available resources and capabilities

Outputs:

Selected UAV mix
Optimized Data Collection Plan

A notional UAV Mission Management System might require:

Inputs:

Selected UAV mix
Data Quality Feedback

Outputs:

Automated Air Tasking Orders
Dynamic Retasking
Multi UAV Coordination

A notional Intelligent Information Management System might require the following:

Inputs:

UAV sensor data and signals
Adjacent Systems: piloted aircraft, satellites

Outputs:

Intelligent Data Fusion, Correlation, and Integration

Examples:

Target Priorities
Optimal Target Allocation and Distribution
Synchronization of Fires

2.3 UAV Requirements Study Findings

Our needs analysis identified some key missions and capabilities for the organic BE UAVs. The operational scenario, discussed in paragraph 2.2.1 and the identified critical missions further allowed us to investigate some critical time - space relationships. We found that the speed for BE UAVs may have been underestimated along with their altitudes, and range requirements. Additionally, the number of key targets that the BE may face in the future may have been underestimated as well.

2.3.1 FINDING: Required BE Organic UAV Speeds may need to be much faster than originally thought.

The results of the rudimentary time - distance calculations indicate that the BE organic UAV velocity may need to be at least 4 x that of the Advanced Fighting Vehicle's (AFV) Ground Speed (~ 400 kph or 248.5 mph). Current ground speed of the AFV's is estimated to be approx. 100 kph. The equations and the time distance calculations are included below in figure 4.

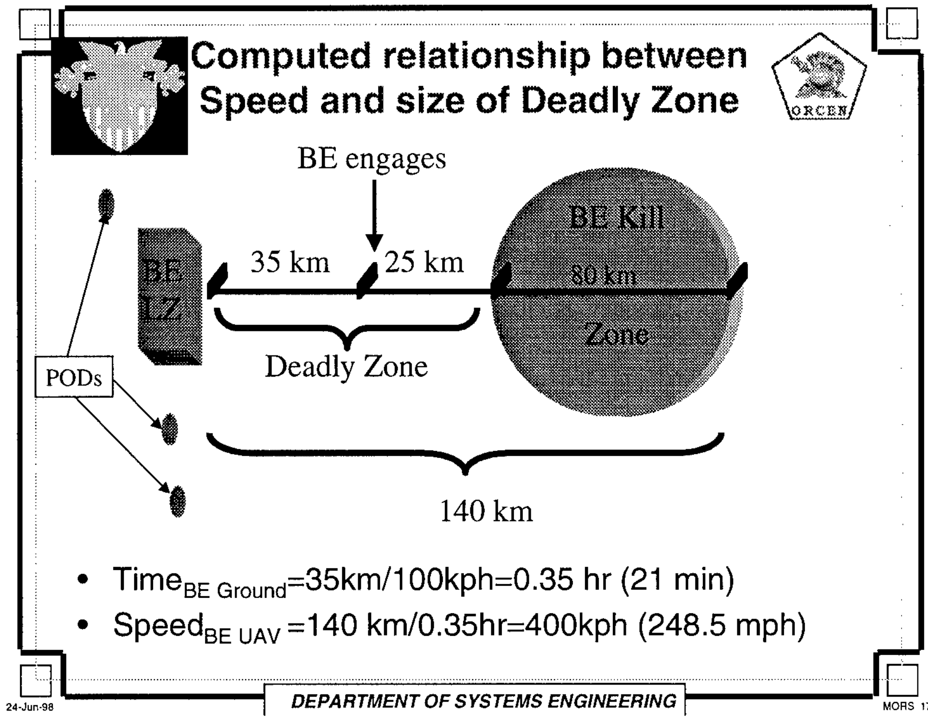

Figure 4: Time distance calculations

2.3.2 FINDING: Size of the BE Deadly Zone may be under estimated.

The historical data obtained from MG Scales' Cycles Of War[13] indicates an exponential relationship between unit velocity (independent variable) and size of "deadly zone" (dependent variable). See Appendix G. If this relationship continues to hold true, the BE advance fighting vehicle ground speed requirements suggests a much larger deadly zone. A much larger deadly zone will have dramatic increases on UAV speed requirements (which will most likely have to be >>400 kph); the length of time of the Decisive Phase; the range and positioning of reach back assets and indirect firing Pods; the location of the BE insertion LZ, and the BE engagement range.

2.3.3 FINDING: BE UAV altitude may be greater than 400 feet (120 m) AGL[14]

We considered some simple trigonometric relationships to determine line of sight (LOS) vs. altitude calculations using a round earth and no obstacles. LOS is only ~ 40 km at altitude of 120 meters. When terrain masking, and other line of sight blocking obstacles are considered, the UAV altitude requirements become much greater. See Appendix E.

[13] MG Scales Cycles Of War, Armed Force Journal International, July 1997
[14] The Army After Next Battle Force, Army After Next Tactical Workbook, 2 JAN 97 pg 16

2.4 UAV Requirements Study Issues

Some of the major issues addressed were: on board vs. off board processing of the information; quantity, quality, and timeliness of the required information; range of autonomous control of the UAVs; and the stealth vs. performance vs. cost tradeoffs.

2.4.1 ISSUE: UAV Data Processing Requirements

A significant tradeoff to consider may be on-board vs. off-board processing. On-board requires increased time for data fusion and may increase payload and physical space requirements, but may reduce communication bandwidth and signature requirements. The opposite may hold true for off-board or distributed processing.

2.4.2 ISSUE: Information Quality and Quantity Necessary for Common Relevant Picture

An additional tradeoff may be between near simultaneous or real-time data/signals vs. analyzed, processed, interpreted, and possibly delayed information and knowledge. The closer to real time the data is transmitted the less likely the data will contain the required knowledge. Some related issues are the reliability of data fusion, the correlation of the data, the confidence in the information/knowledge, and integration of all the data.

2.4.3 ISSUE: Control of UAVs

Another potentially significant tradeoff may be Fully-autonomous vs. manually controlled. The main consideration is the workload must be neutral for the Commander. We feel the UAVs will operate in an autonomous mode whenever possible with manual override on demand. Autonomous operation will require an understanding of mission, commander's intent, and continuous communications with supported units and lateral systems.

2.4.4 ISSUE: Stealth requirements

Stealth requirements will most likely have to be balance and traded off between aerodynamic performance, engine power, air speed, airframe size, all weather capabilities, and cost. Simulations currently play UAVs as impossible to detect. This will more than likely be untrue. A tradeoff analysis should be done to look at what the potential implications and tradeoffs are in cost, complexity, stealth, performance, and cost. Will performance characteristics require less than 100% stealth?

2.5 Changing How We Think About UAVs

The current paradigm for developing AAN UAVs appears focused on understanding current UAV capabilities, and projecting into the future what should be possible. This methodology was instantiated in the December 97 Wargames as players

Such an approach may suggest new UAV requirements, however it could also prevent designers from developing UAV alternatives or forces with "out of the box" capabilities that are significantly different from current UAV prototypes. Such creative designs are

possible when designers "outscope" [15] or think outside the boundaries of what was thought to be the original problem.

An alternative paradigm that could outscope current UAV designs might involve generating hypothetical situations where information, firepower, or both are needed and then assessing what roles UAV might play in addressing those needs.

As an example, consider the following tactical situation:

A Battle Unit commander is given an offensive mission and begins planning by reviewing enemy and friendly force dispositions on a tactical C^3I system. After studying the tactical situation on the LCD map display, the commander finds that intelligence information has not been updated within the past 8 hours in a terrain and vegetation masked area at a range of 10 kilometers along his planned march route.

To eliminate this tactical "blind spot" the battle unit commander highlights the area on the map and selects the menu item "Update intelligence information in this area". After approximately 5 seconds, a system dialog menu appears with the following information:

"The information in this area is over 8 hours old and there are currently no friendly intelligence sources in this area. Please select one of the following:

1. ***Obtain a continuous, real-time update*** (availability: within 10 minutes of request; max duration: 60 minutes)
2. ***Scheduled updates at regular intervals*** (availability: within 5 minutes of request; intervals: 2 to 20 minutes; frequency: 2 to 10 updates)
3. ***Obtain a one-time update*** (availability: within 2 minutes of request)"

The commander is on a tight schedule and estimates he will be in the "blind spot" within 20 minutes. He then requests an immediate update with 5 scheduled updates at intervals of every 2 minutes. Once the request is confirmed, the commander issues an order to move out in the direction of the objective.

Two minutes later, the commander receives an initial update indicating a negative enemy report. However, two updates later, additional information is received from aerial sensors (and confirmed by the S2) that acoustic and thermal sensors now indicate mechanized forces are likely well concealed within the surveyed area.

Armed with this new information, the battle unit commander now makes a tactical decision to bypass the possible threat and take a slightly longer tactical march route that avoids blind spot. Although the route is longer, it will assure that the unit will arrive in the objective at the prescribed time.

To reduce risk while passing near the potential threat area, the battle element commander decides to request a continuous, real-time update. As an additional measure, he requests that the real-time information be also fed to a supporting artillery unit fire direction center so targets can be identified and easily destroyed if the unknown elements changes its current disposition and engages in hostile activity.

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[15] Sage, Andrew P., Systems Engineering, John P. Wiley and Sons, 1992 p.60

The above situation reveals several characteristics about the nature of information commanders will need from C^3I systems in the Army After Next:

- **Information needs:** Tactical commanders will likely not have the time or staff necessary to simultaneously monitor many real time information sources. Instead, commanders will likely be very busy doing commander's business: planning, communicating, executing, and assessing. Because of this, commanders may request information choices in a range from continuous and "real-time" too infrequent. Between these ends of the spectrum are discrete information updates at regular intervals, or perhaps information updates that are triggered by significant events, such as when a unit under surveillance changes its stationary disposition and begins to move.

- **Information costs and value:** Commanders will need to be informed about associated costs for information in terms of accuracy, time to collect, process and disseminate. Once collected and processed, information must be synthesized and integrated with existing information to add value in terms of relevancy and accuracy in the commander's situational awareness. Unit commanders who request such information will need an estimate of this "meta information" to establish realistic expectations about when enough information will be available to execute the mission.

- **Information management:** Commanders need a system that manages information assets and provides reasonable, contextualized choices in order to make good decisions. Choices must be tailored to the tactical situation at hand while hiding the details of *how* the information will actually be collected.

The above situation illustrates that many interconnected systems will likely be needed to support such a spectrum of information requirements. In this light, UAVs might more broadly be seen as aerial platforms that can deploy and communicate with other "adjacent" information and lethality systems to support an advanced C^3I system.

Other "adjacent systems" UAVs must interoperate with might include:

- **human intelligence sources:** UAVs should be able to be controlled and exchange information with deployed HUMINT sources.
- **stationary ground based sensors:** UAVs should be able to deploy and exchange information with ground based sentry sensors (visual, thermal, acoustic, electromagnetic, etc.).
- **geocentric space-based sensors:** UAVs should be able to update and exchange information with space-based sensors. By doing this, information collected by UAVs can continuously preserved even if the UAV is lost. Likewise, UAVs might download information and act as a relay station if weather is expected to prevent continuous satellite communications in an area.
- **manned aerial vehicles: :** small, "disposable", "special purpose", or low power/high endurance UAVs might be quickly deployed to an area via manned aerial vehicles. UAVs might also exchange targeting information with manned

aerial vehicles upon entering an area under UAV surveillance, supplementing the manned vehicle sensor suite while reducing UAV payloads and providing more "time on station".

- **manned ground vehicles and sensors:** smaller, "disposable" UAVs might also be quickly deployed and controlled via manned ground vehicles. Such UAVs would likely also feed information directly to the deploying unit.
- **unmanned ground vehicles and sensors:** smaller, lower cost, or "disposable" UAVs might also be quickly deployed and controlled via unmanned ground vehicles in order to extend the sensor suite.
- **Indirect fire and ground based missile systems:** small, "disposable", "special purpose", or low power/high endurance UAVs might be quickly deployed to area via indirect fire or ground based missile delivery systems. UAVs might also exchange targeting information with incoming artillery and missiles, reducing UAV payloads and providing more "time on station".

Viewed this way, UAVs could have several potential roles in the Army After Next:

- as data collection for continuous and discrete information,
- as data repositories and relay stations,
- as delivery vehicles air and ground based munitions,
- as delivery vehicles air and ground based sensors,
- as delivery vehicles for smaller, disposable UAVs

Several of these roles, support relationships, and capabilities are currently being explored and played in AAN war games. However, others are not, most likely because they do not easily conform with existing UAV prototypes.

Finally, force designers must look beyond the "sensors" and consider the "brains" of the AAN command and control system which UAVs and other systems will feed. The "brains" of the system will need to determine:

- what information collection resources are available for the commander;
- how information collection resources can be optimally scheduled and controlled;
- how collected information can be integrated and synthesized with information already at hand; and
- how information can be organized and optimally presented to the commander in the least amount of time.

3 Modeling Analysis

3.1 Current AAN Modeling Environment

The Army After Next wargames employ several simulation modeling tools to help adjudicate the outcome of moves by the player teams. These models are run as stand-alone simulations in a batch processing mode. Player teams provide their input to the modeling cell; the modelers do their best to quickly input the appropriate data for their particular model; emerging results are fed back to the white cell for final adjudication; then the results are briefed to the player cells.

This modeling environment has several inherent problems. First, there is a "translation" problem between the player teams and the modelers. It is very difficult for the modeling cell to fully understand the intentions of the players and then to correctly implement those plans in the simulations. This problem is exacerbated by the physical separation of the player teams and the modeling cell; there is minimal feedback between these cells.

A second problem is the amount of time that is required to process each move. The modeling cell is constantly under pressure to produce quick results. With only a few hours to build, troubleshoot, run, and analyze the scenario for a given move, errors are likely, and detailed analysis is impossible. Given the current time cycle, it is also nearly impossible to run and analyze the number of trials that would be necessary to produce statistically defensible results. As a result, it is possible that the adjudication of any particular move could be based upon simulation results which do not represent what would happen the majority of the time if multiple replications of the simulation were run and analyzed.

The lack of interaction between the models is a third problem. Each simulation is run in a stand-alone configuration, and since each has a different modeling focus, it is likely that the results of the various models will diverge over time. It is then up to the adjudicators to interpret and meld the results of multiple models in order to determine the outcome of the move. Once again, this is difficult to do accurately in the sort time required between subsequent moves.

The final problem that the present modeling environment presents is the lack of real-time feedback to the player teams. To many of the players, the modeling effort is a black-box; they see their input go into the modeling cell and a number of hours later see the results come back out, but they have no idea what is going on "behind the door" in the modeling and adjudication cells. In addition, the teams are rarely afforded the opportunity to modify their moves based on emerging modeling results, so some of the dynamics of battle are absent. As a result, it is likely that some potentially important insights into the Army After Next are being lost.

3.2 The Role of EADSIM

One of the primary analytic tools being used for modeling by the Army After Next is a simulation package called Extended Air Defense Simulation (EADSIM)[16]. Initially built as an air defense model, it is excellent for simulating aircraft and anti-air systems. In its present form EADSIM also does a very good job of modeling sensors, detections, communications, and various missile systems. We surveyed multiple organizations within DoD that are involved in UAV modeling and analysis and found that EADSIM is the only modeling tool that is in widespread use. For these reasons, EADSIM is a good choice for simulating UAVs for the Army After Next.

EADSIM also has the capability to interact with other simulations in a Distributed Interactive Simulation (DIS) networked computing environment. This allows different simulations to model the aspects of the future battlefield for which they are best suited, to dynamically interact, and then to produce a single outcome for a given scenario (rather than an outcome from each of the different models which must be manually synthesized.) To the best of our knowledge, this capability has not been exploited in any AAN modeling efforts.

3.3 Initial EADSIM Results

To begin our simulation analysis, we obtained the EADSIM data files that were produced during the Nov-Dec AAN tactical wargames[17]. From this data, we constructed a scenario depicting a Battle Element deploying, acquiring, and subsequently attacking advancing Red forces[18]. Our objectives during this effort were to:

- Evaluate the usefulness of EADSIM as a UAV modeling environment
- Construct an AAN type scenario at the Battle Element level that can be used for subsequent analytic efforts
- Quantify the actual contribution of Battle Element UAVs toward mission success
- Seek to identify design issues that may impact future AAN UAV development
- Explore EADSIM's DIS capabilities

The first issue we identified was the need to validate the EADSIM data that is being used for AAN scenarios. We found that the parameters for many of the data elements used in tactical wargame were still set to their default values. In particular, parameters such as *Probability of Detection* and *Probability of Kill* required close examination. We also revised many other values such as the maximum speed of the UAVs, the radar cross

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[16] EADSIM is produced by Teledyne-Brown Engineering under contract by the U.S. Army Space and Missile Defense Command (SMDC), Attn: CSSD-BC-T, P.O. Box 1500, Huntsville, AL 35807

[17] Data files we provided by Ms. Pam Caruso, from the Space and Missile Defense Battle Lab.

[18]The scenario details are several hundred pages long and can be found at http://www.orcen.usma.edu/papers/fy98/aan/.

section of various systems, and the ranges of various sensors. The parameters of the systems we used are included in the scenario description. In order for EADSIM to produce *any* meaningful results, it is critical that the model elements reflect, as realistically as possible, what we believe to be the key characteristics of AAN systems. This will require a methodical validation effort.

In the scenario we constructed, a Battle Element deployed from a significant distance (appx. 400 km), in order to attack and destroy the lead battalions of an advancing Red force. Once they had successfully landed, Battle Element attempted to acquire and subsequently engage targets with tactical missiles. Higher level Battle Force commanders, UAVs from echelons above Battle Element, long range reach-back fires, and Red air defense were also incorporated.

For our base case, we ran a series of trials where the Battle Element could acquire targets in three ways: via sensors on the Battle Element's Advanced Fighting Vehicles (AFVs), from links to other Battle Force sensors (representing the living-internet), and via the Battle Element's organic UAV. We logged the number of Red and Battle Element kills. Then, in an effort to quantify the contribution of the Battle Element UAV, we ran another series of trials where that UAV was eliminated, and then compared the results to the base case. From this experiment, we were able to draw a number of useful conclusions.

The first thing to note is that within a given series of trials, there was tremendous variability in the outcomes[19]. Closer investigation reveals why. When the Battle Element was detected before it landed, or when the Battle Element Commander was killed early in the fight, the battle element performed very poorly and was devastated by long-range Red fires. On the other hand, when the Battle Element was able to successfully deploy, remain undetected, and fire their first salvo as a near "surprise attack", they had tremendous mission success. This provides several important insights:

- If an ambush type attack is desired, stealth is critical. When the enemy has *any* sort of long-range sensors (particularly airborne or space-based sensors), complete surprise will be difficult to obtain. In our scenario, we used very small radar cross sections (RCS) for both the AFVs and the AAFs and used terrain masking to hide the Battle Element as much as possible, but the deploying force was still detected enroute by Red airborne sensors nearly 40% of the time.
- Command, control, and communication must be decentralized. In our trials, when the commander's AFV was killed, the Battle Element quickly ceased to engage enemy targets. This was because target assignments for any targets coming from external sources were all made by the commander (equivalent to a modern Fire Direction Center). This sort of "critical node" must be avoided.

Because of the high variability in the initial data, there was no evidence that the battle element UAV contributed to the success of the Battle Element. However, when we removed the trials in which the Battle Element was detected and destroyed before

[19] Details of the analysis are at Appendix C.

effectively engaging the Red forces, there was some evidence that the employment of an organic UAV contributed to an increase in the number of Red kills. Substantially more trials would be necessary in order to confirm this.

We also spent some time evaluating the sensitivity of our results to the somewhat arbitrary Probability of Detection that we had to assign to every system. Based on some initial testing, our hypothesis was that the outcome of the scenario would be very sensitive to these probabilities. We conducted an experiment which found, however, that the outcome was relatively insensitive to the detection probabilities[20]. This is good news, since detection probabilities are difficult to predict with precision for future systems.

Another observation we made during our experiments is that the altitude at which the Battle Element UAVs are designed to operate has a direct impact on the ability of those UAVs to acquire distant targets. We found that terrain masking and ground clutter prevented the sensors on smaller, lower flying UAVs from identifying Red targets that were located 25-100 km from the Battle Element[21]. However, when we adopted a larger, higher flying UAV (we used an altitude of 5000 feet), many of those same targets were detected and could be engaged. This problem is compounded in difficult terrain; the masking effect can only be overcome by using higher flying UAVs with more powerful sensors. The related trade-off is that as the UAV's altitude and size increases, so does the probability that it will be detected (and possibly engaged) by Red forces.

Reachback fires also played an important role in this simulation. We found that high-flying UAVs could detect many targets that were out of the range of the Battle Element weapons. In nearly all the scenarios, the Battle Force expended its entire allocation of long-range missiles in the early stages of the 2 hour battle.

We also noted that the radar sensors on the Advanced Fighting Vehicles were completely ineffective against ground targets; they are unable to detect any targets at sufficient range to be useful. We did not evaluate the capability of these sensors to detect aerial targets.

This initial scenario is relatively small but can serve as a baseline for future research. In particular, it can be used to interact with a Janus based ground scenario to obtain more realistic interactions between ground based systems.

3.4 Modeling Issues

Several important modeling issues need to be addressed. First, as alluded to in the preceding section, data validation and subsequent scenario validation and verification are critical if the simulation models are to produce credible results. Someone needs to take a close look at all the entities in the models that are being used, and ensure that those elements accurately represent future AAN systems. The implementation of the scenarios must also be scrutinized to ensure they reflect evolving AAN doctrine.

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[20] Details are at Appendix D.

[21] For sample calculations, see Appendix E.

Second, through our modeling experience we've learned that while EADSIM is a very capable, useful modeling tool, it is also extremely complex. The learning curve is very steep. When building or analyzing a scenario, seemingly minor modifications often create unexpected second and third order interactions to take place. It often takes a careful detailed analysis in order to determine why a particular event is occurring (or failing to occur.) For this reason, it is not advisable to attempt to quickly generate a scenario, run it, and rapidly analyze/present the results, unless a corresponding "post-game" analysis is also conducted that investigates *why* things turned out the way they did. Insights gleaned from a few rushed trials are likely to be misleading.

Third, we mentioned previously that the variance in the outcomes for our trials was quite high. This has a direct implication on the number of trials which must be run in order to draw conclusions with any level of statistical certainty. Our base case trials indicated that in order to be 95% confident that we were correctly identifying the average number of Red kills, we would have to conduct 111 runs of the simulation[22]. Conducting and analyzing this number of trials is very time consuming, and impossible to perform during an AAN exercise. Once again, these results indicate the need for thorough post-exercise analysis.

Compounding this problem with the number of trials required is the fact that EADSIM does not have any post-processing tools for Monte Carlo simulation runs. Therefore the required data must be captured from each individual trial, manually extracted, and then aggregated by the analyst. This process is error prone, and could easily result in corruption the simulation data. If EADSIM is to be used for true Monte Carlo simulation analysis, appropriate post-processing tools must be developed.

[22] See Appendix F for calculations.

4 Conclusions

4.1 Key UAV Requirements

Our mission and requirements analysis and subsequent functional decomposition found the most important UAV missions to be: reconnaissance, tracking and surveillance, electronic warfare, identification of friend or foe, target acquisition and designating, down to the individual vehicle level, battle damage assessment, and communication processing. Additionally, we found other critical UAV missions to be: confirming data from other sensors; enhancing unit security; supporting urban warfare; and performing NBC detection. It is also critical that UAVs be capable of operating in all weather conditions. The study's requirement's survey of senior AAN personnel supported our findings.

4.2 Important Modeling Considerations

As discussed in the previous sections, data validation and subsequent scenario validation and verification are critical if the simulation models are to produce credible results. The implementation of the scenarios must accurately reflect evolving AAN doctrine. We found EADSIM to be a very capable, useful modeling tool, but also extremely complex. The learning curve is very steep. When building or analyzing a scenario, seemingly minor modifications often created unexpected second and third order interactions. It took a careful, in depth, and detailed analysis to determine why a particular event occurred (or failed to occur.) Quickly generation and analysis of scenario, is not advisable. Post-game analysis should be conducted to investigate *why* things turned out the way they did. Insights gleaned from a few rushed trials may be very misleading. The variance in the outcomes for our trials was quite high. High variance has a direct implication on the number of trials which must be run in order to draw conclusions with any level of statistical certainty. Conducting and analyzing large number of trials is very time consuming and may not be possible to perform during an AAN exercise. However, post-exercise analysis should be done.

4.3 Other Conclusions

As the organic BE UAV requirements evolve, the time, space, and altitude relationships should continue to be investigated, modeled, and simulated to gain clearer and more robust insights into detailed system requirements, specifications, and system integration issues. The findings from our study suggest four potential areas for further investigation. The four main areas are UAV speed, altitude, range, and the number of target acquisition and designation requirements. These are certainly not the only four areas, but are areas which came to light as a result of our investigations.

Additionally, our study seemed to indicate a UAV centric attitude towards identifying and defining UAV requirements and force structures. Force designers should consider

more than the UAV sensor packages, engines, and airframes. More consideration should be given to the super and lateral system interface requirements and to the integration of all the knowledge ("the brains" of the AAN command and control system which UAVs and other systems will feed), before force structure analysis begins. The living Internet and the Intelligence Surveillance Reconnaissance (ISR) structure will most likely be a part of "the brain" and be critical in the support of the UAV structure.

5 Future Research

Continued requirements analysis for all Battle Force echelons (Force, Unit, and Element) should be pursued. And requirements analysis of the super and lateral system interfaces and integration issues should be conducted to insure proper identification, specification, and delineation of requirements. After the requirements are analyzed and properly defined, an integration effort would be advisable and more easily completed. Continued investigations into the modeling and simulation of the AAN C^4ISR infrastructure should also be pursued. Perfect, real time, and instantaneous information is not a luxury we should assume and base our further investigations on.

Appendix A: UAV Missions/Roles Survey Form

UAV Missions / Importance			Importance to Echelon			
			EABF	BF	BU	BE
UAV Missions	Enable Common Relevant Picture	Gather Wide-Area RSTA (Units/Formations)	4	4	3	1
		Gather Detailed RSTA (Individual Vehicles)	2	3	4	4
		Gather PIR Data for Commander	2	3	3	2
		Supplement Space Systems	3	3	2	1
		Interoperate with Joint (Land/Sea/Air) Systems	4	4	4	3
		Confirm Data From Other Sensors	3	4	4	4
		Facilitate Data Fusion	2	3	3	2
		Minimize Sensor-to-User Data Latency	2	3	4	4
	Enhance Military Effectiveness	Perform Electronic Warfare Missions	3	4	3	1
		ID Landing Zones	1	2	3	4
		Enhance Unit Security	1	2	3	4
		Target Enemy	2	3	4	4
		Cue Force XXI and AAN Systems	3	3	3	3
		Establish Sensor-to-Shooter Links	2	3	4	3
		Limit Collateral Damage	1	1	2	3
		Perform BDA	2	2	3	4
		Execute Counter-Recon Missions	2	4	3	2
		Allow Commander a High Degree of Flexibility	2	3	4	4
	Perform Special Missions	Support Strikes on Key Targets	4	4	3	3
		Conduct UAV-to-Ground Attack	2	4	4	4
		Conduct UAV-to-Air Attack	2	4	3	2
		Conduct Non-Lethal Attack	0	2	3	3
		Activate Enemy Sensors / Systems	1	3	2	2
		Execute Counter-Mine Operations	2	2	3	2
		Perform Psyops Missions	4	3	1	0
		Perform NBC Detection	2	3	3	4
		Support Urban Warfare	1	2	3	4
		Perform Terrain Analysis and Digital Mapping	2	2	2	2
		Execute Logistical Resupply	2	3	2	1
		Update Weather Information	1	2	1	1
		Back Up Satellite GPS System	3	2	2	2
		Relay Communications	4	4	4	3
	Maintain Feasibility	Be Survivable	4	4	3	2
		Operate in All Weather Conditions	4	4	4	4
		Remain Logistically Supportable	3	3	3	3
		Keep UAVs "Expendable"	2	2	3	3
		Be Affordable	2	2	3	3

Importance for Battle Force Mission Success	4 = Critical 3 = High 2 = Moderate 1 = Slight 0 = Not Important

The survey instructions asked the participants to:

- modify the ratings to reflect their opinion concerning the relative importance of BF, BU, and BE UAV missions
- suggest other missions that UAVs might perform
- identify the 5 “most critical” UAV missions
- provide other comments/feedback

Appendix B: UAV Missions/Roles Survey Results

Feedback: Response to this survey was not strong. Over 20 key AAN participants agreed to participate, however, in spite of several follow-up reminders, results were received from only 9 individuals. The only "senior leader" who sent me information was COL Starry. As a result, the subsequent analysis is based on 10 data points: 9 Tactical Wargame participants, plus my initial input. Because of the low number of responses, this analysis concentrates on summarizing the data and looking for any insights that may be useful in subsequent UAV design work.

Results: A sheet that shows the averages responses of the 10 participants (the raw data) is at the end of this appendix. What follows is a summary of that data, particularly focused on the missions of *Battle Element* UAVs.

TOP 20 Battle Element UAV Missions	
Operate in All Weather Conditions	4.0
Minimize Sensor-to-User Data Latency	4.0
Target Enemy	4.0
Gather Detailed RSTA (Individual Vehicles)	4.0
Support Urban Warfare	4.0
Perform NBC Detection	4.0
Enhance Unit Security	4.0
Allow Commander a High Degree of Flexibility	3.9
Confirm Data From Other Sensors	3.9
Perform BDA	3.9
ID Landing Zones	3.8
Conduct UAV-to-Ground Attack	3.6
Relay Communications	3.2
Establish Sensor-to-Shooter Links	3.1
Support Strikes on Key Targets	3.0
Cue Force XXI and AAN Systems	3.0
Remain Logistically Supportable	3.0
Keep UAVs "Expendable"	3.0
Be Affordable	3.0
Interoperate with Joint (Land/Sea/Air) Systems	2.9

This list reflects the missions that received the highest overall scores in the "numerical rating" portion of the survey. Some "enabling characteristics" (such as, Operate in All Weather Conditions) are mixed in with missions. There doesn't

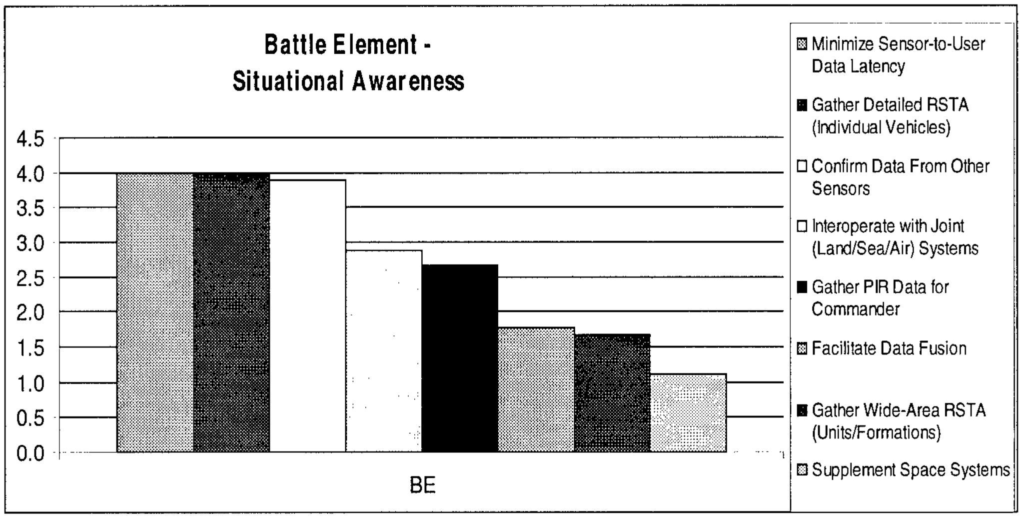
seem to be any particular focus in this list of Critical/Important missions; they include a wide range of significantly different type tasks. Perhaps more important is the list of missions that were not considered critical or highly important. Those missions are probably "nice-to-do" and therefore should not be the focus of UAV modeling and design efforts.

Most Critical Missions: In addition to rating the individual missions, participants were asked to identify the five UAV missions that are the *most important* to overall Battle Force mission success. Ranking the missions beginning with the most frequently selected mission, the results were:

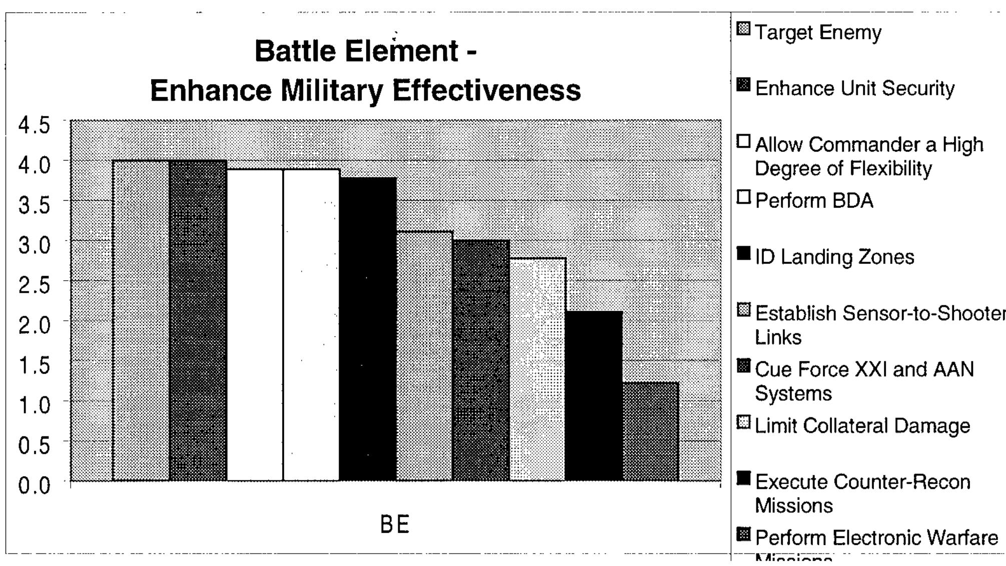
Missions Ranked "Highest Priority" (Decending Order)
Gather Detailed RSTA (Individual Vehicles)
Confirm Data From Other Sensors
Perform BDA
Relay Communications
Support Strikes on Key Targets
Gather PIR Data for Commander
Operate in All Weather Conditions
Target Enemy
Support Urban Warfare
Perform NBC Detection
Establish Sensor-to-Shooter Links
Cue Force XXI and AAN Systems
Conduct Non-Lethal Attack
Back Up Satellite GPS System
Execute Counter-Recon Missions
Activate Enemy Sensors / Systems
Facilitate Data Fusion
Gather Wide-Area RSTA (Units/Formations)

This provides some insight into the missions that we should be focusing on in our design efforts. It is interesting to note that this list differs a bit from the "numerical ratings" in the previous table. This could be due to the fact that the first list focuses specifically on Battle Element UAVs, while the "top five" approach focuses on the overall Battle Force. A combination of the two lists probably presents the best picture of the missions we should focus on.

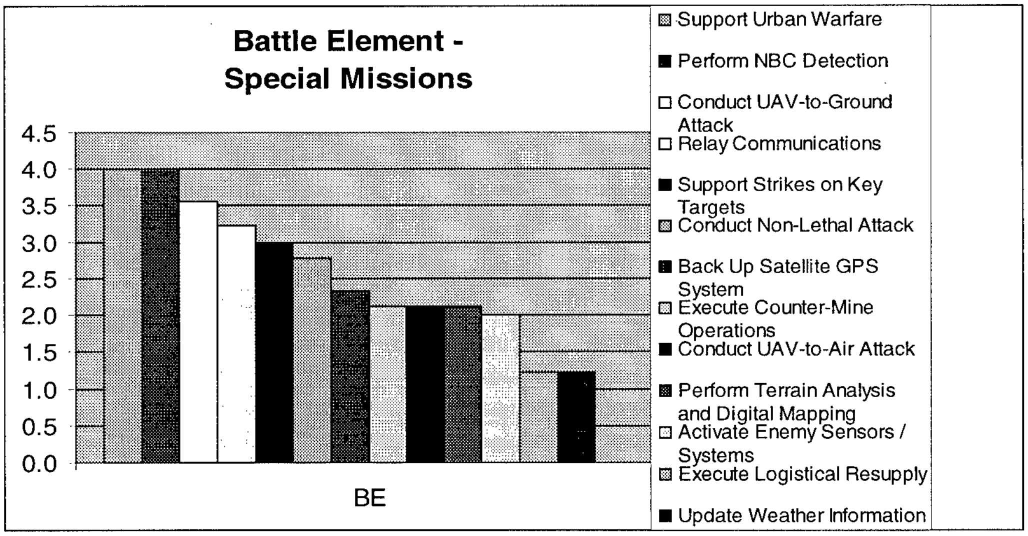
Battle Element UAV Missions (by Category): One other way of looking at this data is by breaking it out within each mission category. The following charts show the Battle Element averages by category:



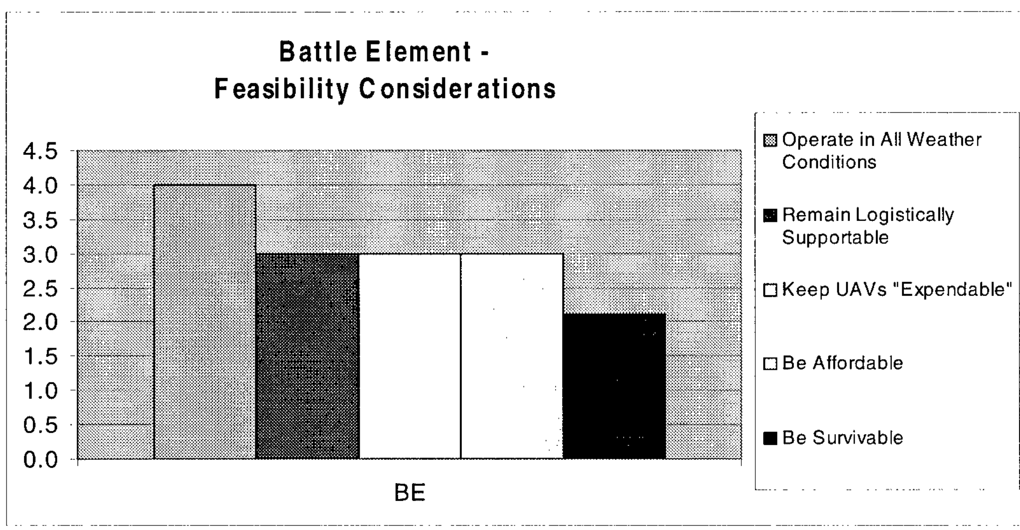
This indicates that the most important role of the Battle Element UAV is to serve as a sensor platform that can gather and rapidly disseminate targettable data down to the individulal enemy vehicle level.



Once again, targetting the enemy was considered one of the most important roles of the lower echelon AAN UAVs. At the same time, enhancement of unit security, an inherently defensive mission, was also considered critical.



Under the category of "Special Missions", supporting urban warfare and performing NBC detection were the two missions that ranked the highest. Both of these missions, however, could require UAVs that are radically different in design from the long-range UAVs necessary to acquire and target enemy systems over in a traditional battle environment.



Battle element UAVs must be capable of operating in all environmental conditions. This has significant implications for mini and micro-UAVs which have a much harder time flying in adverse weather.

Additional Missions: Quite a few additional UAV missions were added by the participants. They were:

Other Possible Missions (from survey participants)	*Air Deliver Remote Sensor/Mine Pay Loads*	1	3	3	1
	ATA Wingman for [manned] ATK or RISTA Aircraft	4	4	3	3
	Ease of Employment	2	2	4	4
	Ultra-reliable systems	3	3	3	3
	Back Up Comm Systems	4	4	4	4
	Gather Friendly / Non-Combatant Data	3	4	4	4
	Gather Wide-Area RSTA (Log Nodes)	4	4	3	1
	Port & Airfield Survey	4	2	0	0
	Locate Friendly Casualties	1	2	3	2
	Support Redundant Comms for Dispersed Forces	4	4	4	3
	Protect ALOCs and Log Bases	3	3	2	2

Other Survey Comments: Perhaps the most valuable information from this survey comes from the additional comments provided by the participants.

- BDA is a classic battlefield problem, one for which we do not have any good solutions right now ... UAV is the most promising.
- BDA is difficult!!! Especially at strategic distance.
- Gathering PIR for the CDR seems to me should be higher priority. PIR is the basis for situational awareness, therefore critical. CDR should be able to influence the CRP, and PIR is how he does that.
- Not sure what our plan for terrain analysis, Wx, back up GPS is ... but these are all critical aspects of METT, and UVs can play a role. Question is how critical is their role. In the case of GPS ... individuals and units can not operate w/out it, therefore it is so critical that maybe this ought to be a critical UV mission.
- Not sure how UAVs do "countermine"
- Not sure what "Allow CDR High Degree of Flexibility" is ... but I know I like flexibility!
- "Operate in All Weather Conditions" may not be doable for micro or mini systems.
- Classic struggle here among missions - Recon, Surveillance, IW, Fire Support, transport, comms, and special missions - results in lack of focus in operational concept and the RDA effort. Therefore potentially you get no decisions (and no systems ala AQUILA); or you get a

system that doesn't do anything well; or you proliferate an unmanageable "family of systems".

- UAV-Ground and UAV-Air attack are equally important if enemy has high air atk helo capabilities
- Some UAVs should be expendable, not all
- Data Fusion is not done on the airframe
- Change "Confirm Data from Other Sensors" to "Refine data from other sensors".
- Attack roles are "extra". Not the purpose of UAVs.
- Change "Back up Satellite GPS System" to "Back Up ... GPS and Communication ..."
- Change "Minimize Sensor-to-User Data Latency" to just "Minimize Data Latency"
- Need more detail on "Support Urban Warfare"
- Change "Relay Communications" to "Support Redundant Comms for Dispersed Forces"
- Add "Protect 3-D Flanks" to "Enhance Unit Security"
- Change "Execute counter-Recon Missions" to "Execute Counter-RISTA Missions".
- Change "Operate in All Weather Conditions" to "....Conditions, Day and Night".

Possible Problems with Survey:

- “Small n” – may or may not adequately capture the values of AAN planners.
- Several participants changed very few of the values in the data section. Therefore the “initial values” probably strongly influenced the results.
- In several instances there was a mis-match between a participant's numerical ratings and his “most critical missions” selections. For example, I noted that several of the missions that were identified as most critical had numeric ratings of 2s and 3s, while other missions that had 4s were not selected at “most critical”. Again, this is evidence that some of the participants didn't spend much time thinking about the numeric rating of the missions.

Conclusions:

This survey information is useful as an azimuth check for our design teams. It demonstrates that the opinions of a number of key AAN participants concerning the roles and missions of UAVs in the Army After Next are in concert with what we have come up with thus far. It also helps clarify the types of UAV missions/roles we should seek to model. The critical missions will become the Measures of Effectiveness for our subsequent modeling efforts. These results also show the sort of roles and missions that are *not* considered critical, and therefore merit less attention during the design effort.

Survey Results: Raw Data

UAV Missions / Importance			Importance to Echelon				
			EABF	BF	BU	BE	Highest
UAV Missions	Enable Common Relevant Picture	Gather Wide-Area RSTA (Units/Formations)	3.8	3.9	3.1	1.7	1
		Gather Detailed RSTA (Individual Vehicles)	2.0	3.0	4.0	4.0	4
		Gather PIR Data for Commander	2.6	3.2	3.4	2.7	2
		Supplement Space Systems	3.1	3.0	2.1	1.1	0
		Interoperate with Joint (Land/Sea/Air) Systems	4.0	4.0	3.9	2.9	0
		Confirm Data From Other Sensors	2.9	3.9	3.9	3.9	3
		Facilitate Data Fusion	1.8	2.7	2.7	1.8	1
		Minimize Sensor-to-User Data Latency	2.1	3.1	4.0	4.0	0
	Enhance Military Effectiveness	Perform Electronic Warfare Missions	3.0	4.0	3.0	1.2	0
		ID Landing Zones	1.0	2.1	3.1	3.8	0
		Enhance Unit Security	1.0	2.0	3.0	4.0	0
		Target Enemy	2.1	3.1	4.0	4.0	1
		Cue Force XXI and AAN Systems	3.0	3.0	3.1	3.0	1
		Establish Sensor-to-Shooter Links	2.0	3.0	4.0	3.1	1
		Limit Collateral Damage	1.0	1.0	2.0	2.8	0
		Perform BDA	2.2	2.1	3.0	3.9	2
		Execute Counter-Recon Missions	2.0	4.0	3.0	2.1	1
		Allow Commander a High Degree of Flexibility	2.1	3.1	4.0	3.9	0
	Perform Special Missions	Support Strikes on Key Targets	3.8	3.9	3.1	3.0	2
		Conduct UAV-to-Ground Attack	1.9	3.6	3.7	3.6	0
		Conduct UAV-to-Air Attack	1.9	3.3	2.9	2.1	0
		Conduct Non-Lethal Attack	0.0	2.0	2.9	2.8	1
		Activate Enemy Sensors / Systems	1.0	3.0	2.0	2.0	1
		Execute Counter-Mine Operations	2.0	2.0	3.0	2.1	0
		Perform Psyops Missions	3.9	2.9	1.0	0.0	0
		Perform NBC Detection	2.0	3.0	3.0	4.0	1
		Support Urban Warfare	1.0	2.1	3.1	4.0	1
		Perform Terrain Analysis and Digital Mapping	2.1	2.2	2.1	2.1	0
		Execute Logistical Resupply	2.0	3.0	2.0	1.2	0
		Update Weather Information	1.0	2.0	1.2	1.2	0
		Back Up Satellite GPS System	3.0	2.2	2.3	2.3	1
		Relay Communications	3.9	4.0	4.0	3.2	2
	Maintain Feasibility	Be Survivable	4.0	4.0	3.0	2.1	0
		Operate in All Weather Conditions	4.0	4.0	4.0	4.0	1
		Remain Logistically Supportable	3.0	3.0	3.0	3.0	0
		Keep UAVs "Expendable"	2.0	2.0	3.0	3.0	0
		Be Affordable	2.0	2.0	3.0	3.0	0

Importance for Battle Force Mission Success	
	4 = Critical
	3 = High
	2 = Moderate
	1 = Slight
	0 = Not Important

Appendix C: EADSIM Simulation Results

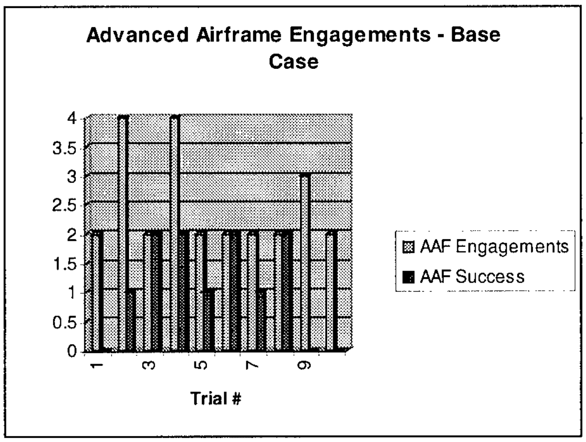
Base Case – Raw Results

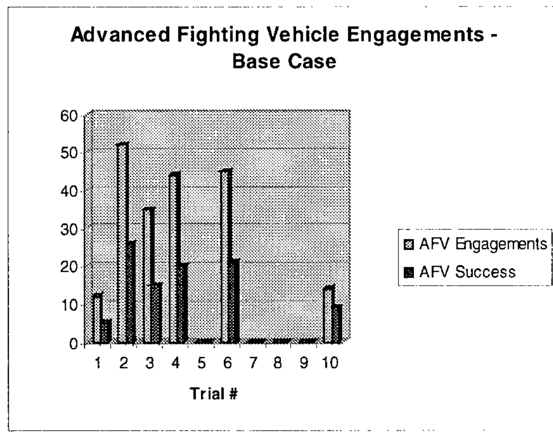
Trial #	Platform	Missile Launch	Success	Dead Target	Fail PK	Intercepted
1	USMA_BE_AAF	2	0	1	1	0
2	USMA_BE_AAF	4	1	2	1	0
3	USMA_BE_AAF	2	2	0	0	0
4	USMA_BE_AAF	4	2	1	1	0
5	USMA_BE_AAF	2	1	0	1	0
6	USMA_BE_AAF	2	2	0	0	0
7	USMA_BE_AAF	2	1	0	1	0
8	USMA_BE_AAF	2	2	0	0	0
9	USMA_BE_AAF	3	0	0	3	0
10	USMA_BE_AAF	2	0	1	1	0
	USMA_BE_AAF StdDev	0.849836586	0.875595036	0.707106781	0.875595	0
	AAF	2.5	1.1	0.5	0.9	0
1	USMA_Blue_AFV	12	5	2	1	4
2	USMA_Blue_AFV	52	26	8	14	4
3	USMA_Blue_AFV	35	15	5	13	2
4	USMA_Blue_AFV	44	20	5	18	1
5	USMA_Blue_AFV	0	0	0	0	0
6	USMA_Blue_AFV	45	21	5	16	3
7	USMA_Blue_AFV	0	0	0	0	0
8	USMA_Blue_AFV	0	0	0	0	0
9	USMA_Blue_AFV	0	0	0	0	0
10	USMA_Blue_AFV	14	9	1	3	1
	USMA_Blue_AFV StdDev	21.47246299	10.1456066	2.913569784	7.6919872	1.64991582
	AFV	20.2	9.6	2.6	6.5	1.5
1	USMA_Blue-ATACMS_500	24	6	2	6	10
2	USMA_Blue-ATACMS_500	24	5	3	8	8
3	USMA_Blue-ATACMS_500	24	5	6	6	7
4	USMA_Blue-ATACMS_500	24	4	8	5	7
5	USMA_Blue-ATACMS_500	24	5	3	4	12
6	USMA_Blue-ATACMS_500	24	3	5	7	9
7	USMA_Blue-ATACMS_500	24	6	1	4	13
8	USMA_Blue-ATACMS_500	24	9	2	7	6
9	USMA_Blue-ATACMS_500	24	4	0	11	9
10	USMA_Blue-ATACMS_500	24	7	5	7	5
	USMA_Blue-ATACMS_500 StdDev	0	1.712697677	2.460803843	2.0682789	2.54732976
	Reach Back	24	5.4	3.5	6.5	8.6

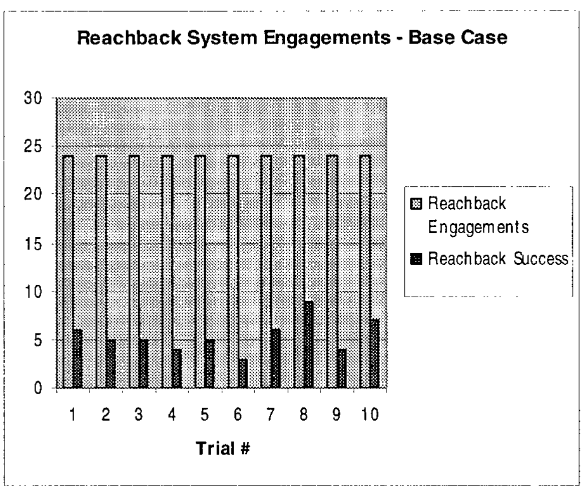
Trial	Platform	Engagements	Missile Launch	BE Kills
1	USMA_Red_Launcher_500k	6	12	5
2	USMA_Red_Launcher_500k	3	6	3
3	USMA_Red_Launcher_500k	8	16	7
4	USMA_Red_Launcher_500k	4	8	6
5	USMA_Red_Launcher_500k	10	20	8
6	USMA_Red_Launcher_500k	7	14	8
7	USMA_Red_Launcher_500k	6	12	9
8	USMA_Red_Launcher_500k	6	12	8
9	USMA_Red_Launcher_500k	6	12	8
10	USMA_Red_Launcher_500k	6	12	5

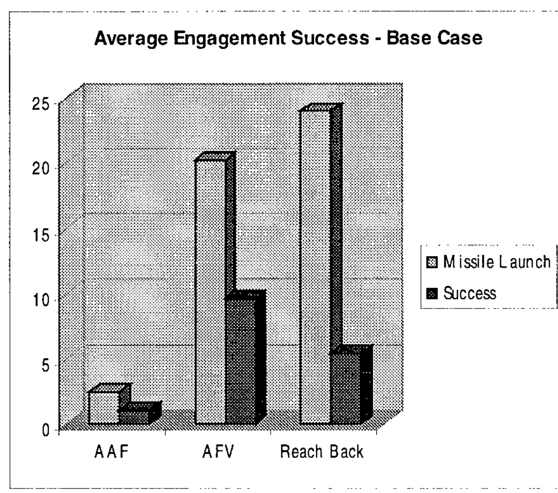
Base Case - Summary Data

AAF Engagements	AAF Success	AFV Engagements	AFV Success	Reachback Engagements	Reachback Success	Total Kills	Percent Red Killed
2	0	12	5	24	6	11	28.2%
4	1	52	26	24	5	32	82.1%
2	2	35	15	24	5	22	56.4%
4	2	44	20	24	4	26	66.7%
2	1	0	0	24	5	6	15.4%
2	2	45	21	24	3	26	66.7%
2	1	0	0	24	6	7	17.9%
2	2	0	0	24	9	11	28.2%
3	0	0	0	24	4	4	10.3%
2	0	14	9	24	7	16	41.0%









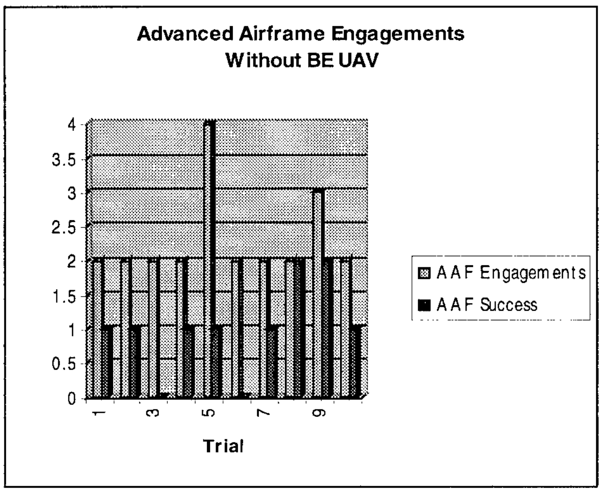
Without BE UAV – Raw Results

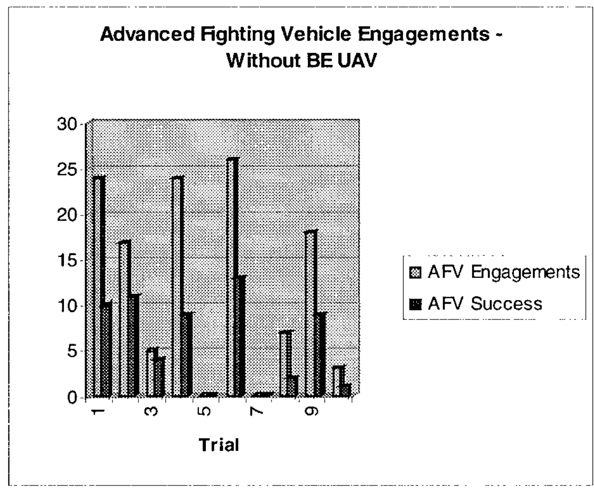
Trial Number	Platform	Missile Launch	Success	Dead Target	Fail PK	Intercepted
1	USMA_BE_AAF	2	1	0	1	0
2	USMA_BE_AAF	2	1	0	1	0
3	USMA_BE_AAF	2	0	1	1	0
4	USMA_BE_AAF	2	1	0	1	0
5	USMA_BE_AAF	4	1	1	2	0
6	USMA_BE_AAF	2	0	0	2	0
7	USMA_BE_AAF	2	1	0	1	0
8	USMA_BE_AAF	2	2	0	0	0
9	USMA_BE_AAF	3	2	0	1	0
10	USMA_BE_AAF	2	1	0	1	0
	USMA_BE_AAF StdDev	0.674948558	0.666666667	0.421637021	0.567646212	0
	AAF	2.3	1	0.2	1.1	0
1	USMA_Blue_AFV	24	10	2	9	3
2	USMA_Blue_AFV	17	11	3	3	0
3	USMA_Blue_AFV	5	4	0	1	0
4	USMA_Blue_AFV	24	9	3	9	3
5	USMA_Blue_AFV	0	0	0	0	0
6	USMA_Blue_AFV	26	13	2	9	2
7	USMA_Blue_AFV	0	0	0	0	0
8	USMA_Blue_AFV	7	2	1	4	0
9	USMA_Blue_AFV	18	9	3	5	1
10	USMA_Blue_AFV	3	1	0	1	1
	USMA_Blue_AFV StdDev	10.46900186	4.998888765	1.349897115	3.754996671	1.247219129
	AFV	12.4	5.9	1.4	4.1	1
1	USMA_Blue-ATACMS_500	24	7	6	5	6
2	USMA_Blue-ATACMS_500	24	5	9	4	6
3	USMA_Blue-ATACMS_500	24	9	3	9	3
4	USMA_Blue-ATACMS_500	24	6	2	8	8
5	USMA_Blue-ATACMS_500	24	10	2	9	3
6	USMA_Blue-ATACMS_500	24	4	6	8	6
7	USMA_Blue-ATACMS_500	24	7	2	8	7
8	USMA_Blue-ATACMS_500	24	8	4	6	6
9	USMA_Blue-ATACMS_500	24	4	7	6	7
10	USMA_Blue-ATACMS_500	24	4	5	8	7
	USMA Blue-ATACMS 500 S	0	2.170509413	2.412928143	1.728840331	1.663329993
	Reachback	24	6.4	4.6	7.1	5.9
	Grand StdDev	10.74580913	3.936419985	2.448551061	3.407395608	2.866573107
	Grand Average	12.9	4.433333333	2.066666667	4.1	2.3

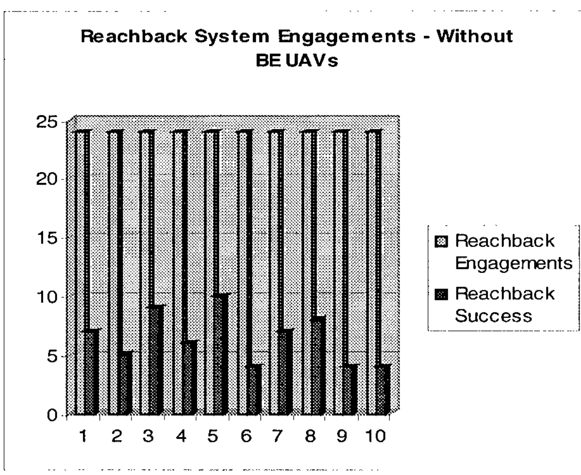
Trial	Platform	Engagements	Missile Launch	BE Kills
1	USMA_Red_Launcher_500k	6	12	5
2	USMA_Red_Launcher_500k	5	10	7
3	USMA_Red_Launcher_500k	6	12	9
4	USMA_Red_Launcher_500k	7	14	4
5	USMA_Red_Launcher_500k	7	14	9
6	USMA_Red_Launcher_500k	6	12	6
7	USMA_Red_Launcher_500k	6	12	9
8	USMA_Red_Launcher_500k	7	14	9
9	USMA_Red_Launcher_500k	6	12	7
10	USMA_Red_Launcher_500k	9	18	8

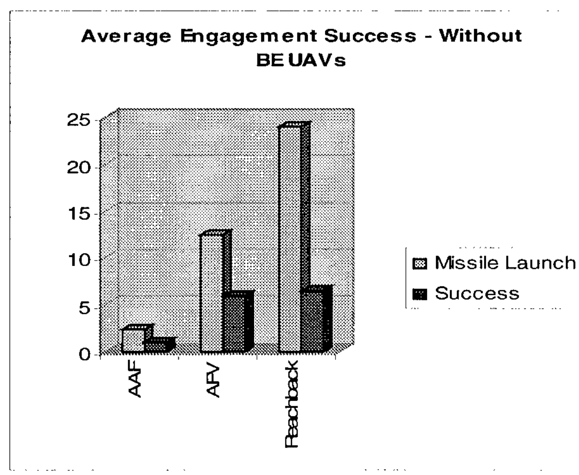
Without BE UAV – Summary Data

AAF Engagements	AAF Success	AFV Engagements	AFV Success	Reachback Engagements	Reachback Success
2	1	24	10	24	7
2	1	17	11	24	5
2	0	5	4	24	9
2	1	24	9	24	6
4	1	0	0	24	10
2	0	26	13	24	4
2	1	0	0	24	7
2	2	7	2	24	8
3	2	18	9	24	4
2	1	3	1	24	4



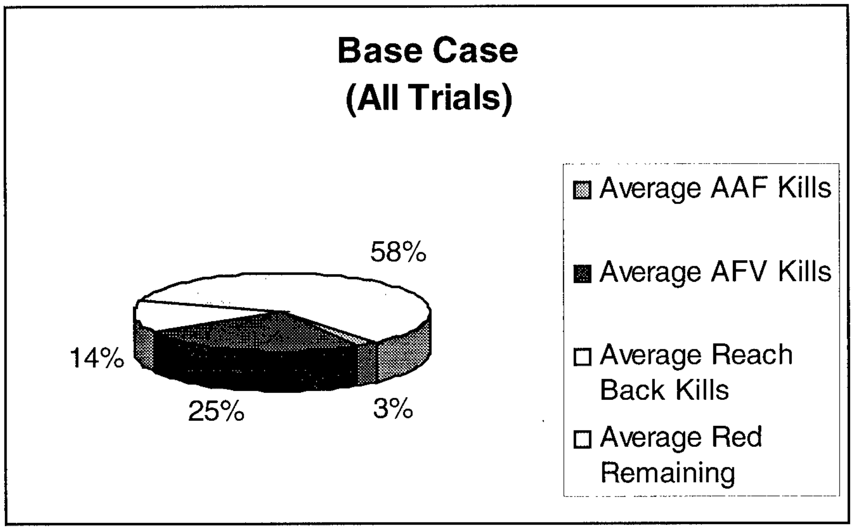


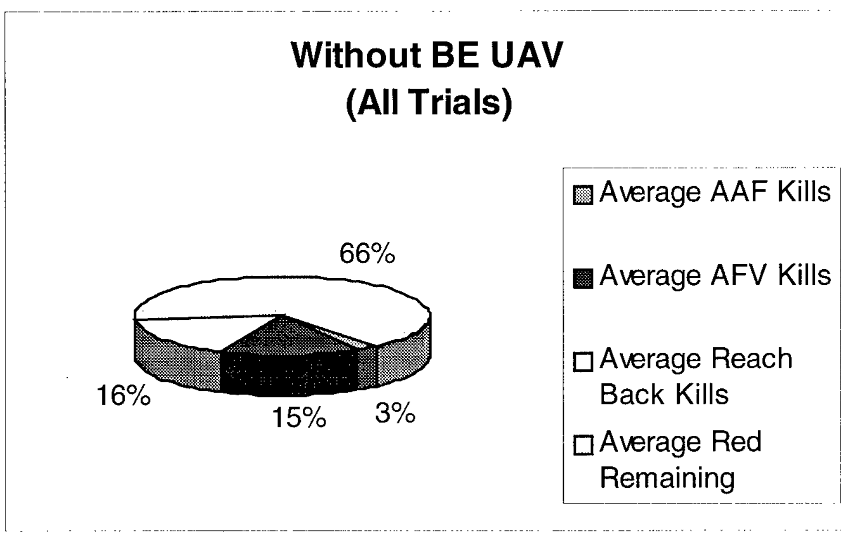




Comparison – Base Case vs. Without BE UAV

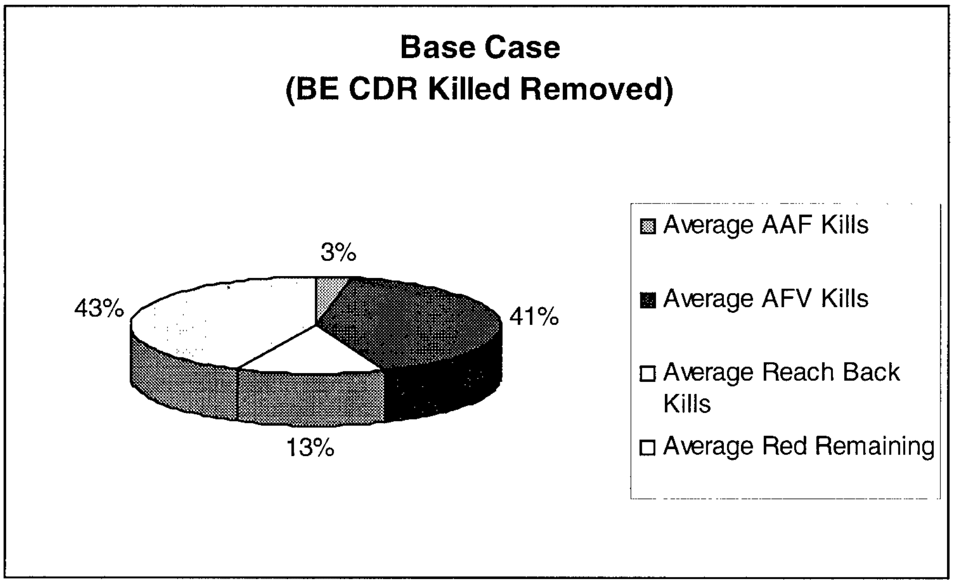
	Base Case	% of Red Killed	W/O BE UAV	% of Red Killed
Average AAF Kills	1.1	2.8%	1	2.6%
Average AFV Kills	9.6	24.6%	5.9	15.1%
Average Reach Back Kills	5.4	13.8%	6.4	16.4%
Average Red Remaining	22.9	58.7%	25.7	65.9%

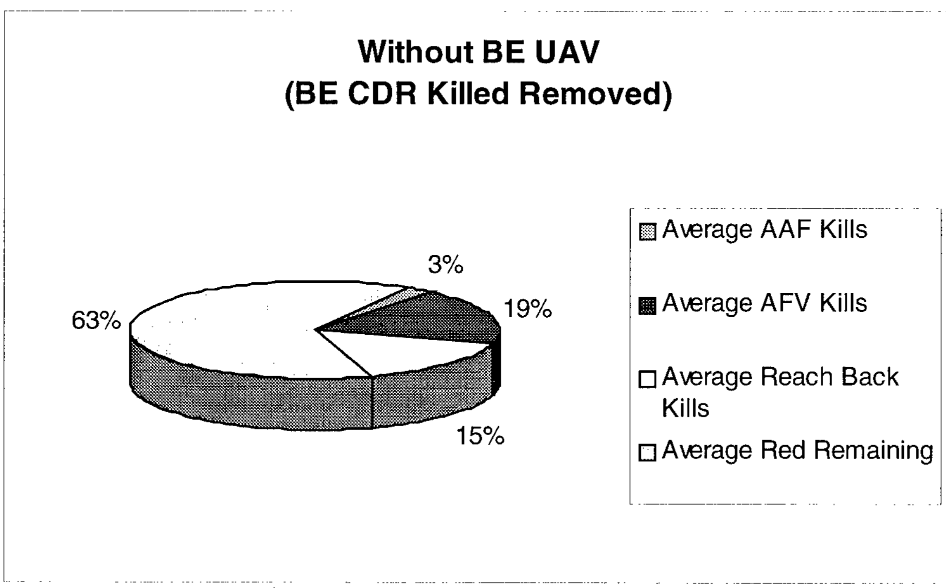




Comparison – Base Case vs. Without BE UAV (undetected entries only)

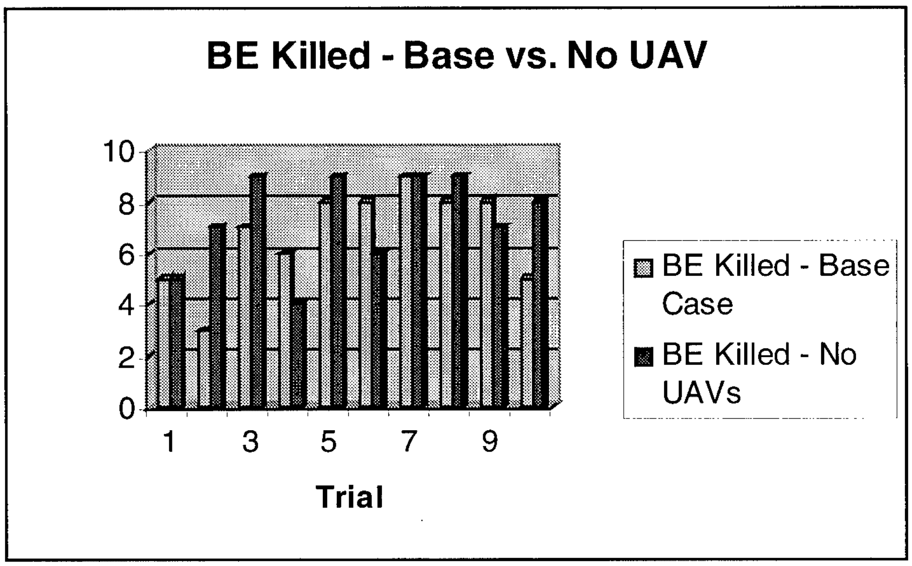
	Base Case	% of Red Killed	W/O BE UAV	% of Red Killed
Average AAF Kills	1.17	3.0%	1	2.6%
Average AFV Kills	16.00	41.0%	7.4	18.9%
Average Reach Back Kills	5.00	12.8%	5.9	15.1%
Average Red Remaining	16.8	43.2%	24.8	63.5%





Blue Losses

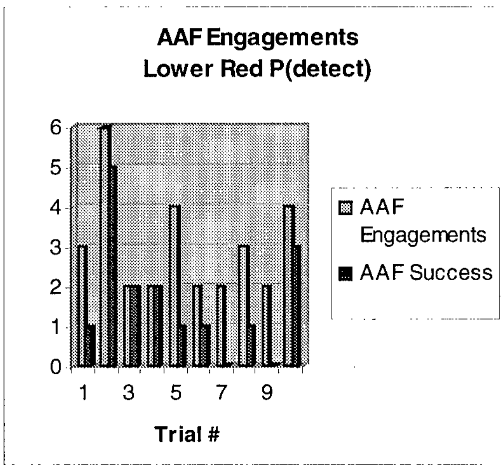
Trial	BE Killed - Base Case	BE Killed - No UAVs
1	5	5
2	3	7
3	7	9
4	6	4
5	8	9
6	8	6
7	9	9
8	8	9
9	8	7
10	5	8

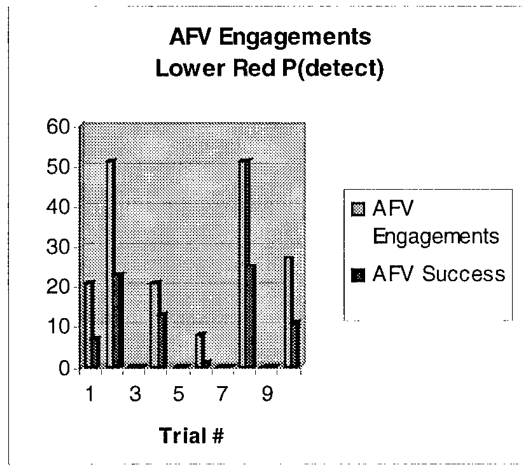


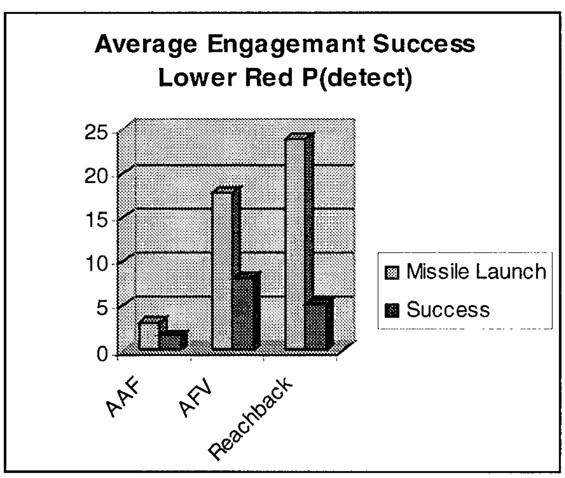
Appendix D: Probability of Detection Sensitivity Analysis

Summary Results – Reduced Red P(D)

AAF Engagements	AAF Success	AFV Engagements	AFV Success	Reachback Engagements	Reachback Success
3	1	21	7	24	9
6	5	51	23	24	2
2	2	0	0	24	5
2	2	21	13	24	3
4	1	0	0	24	6
2	1	8	1	24	1
2	0	0	0	24	5
3	1	51	25	24	5
2	0	0	0	24	10
4	3	27	11	24	5

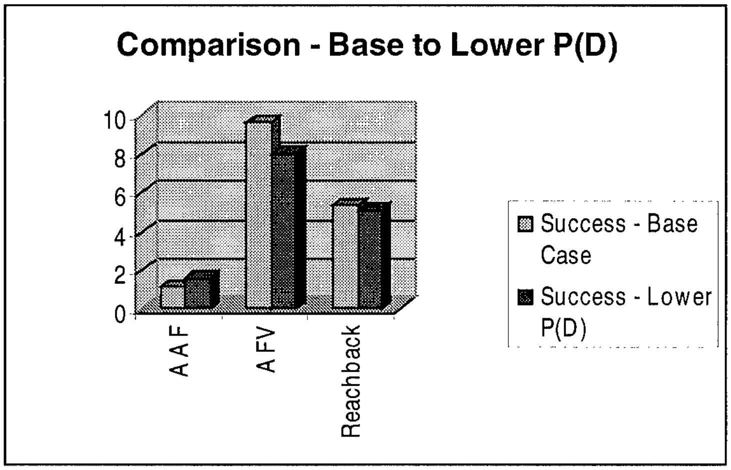






Comparison to Base Case

Platform	Missile Launch - Base Case	Success - Base Case	Missile Launch - Lower P(D)	Success - Lower P(D)
AAF	2.5	1.1	3	1.6
AFV	20.2	9.6	17.9	8
Reach Back	24	5.4	24	5.1



Appendix E: UAV Altitude / Visibility Calculations

The following equations in five below, were used to demonstrate the line of sight at a specific altitude.

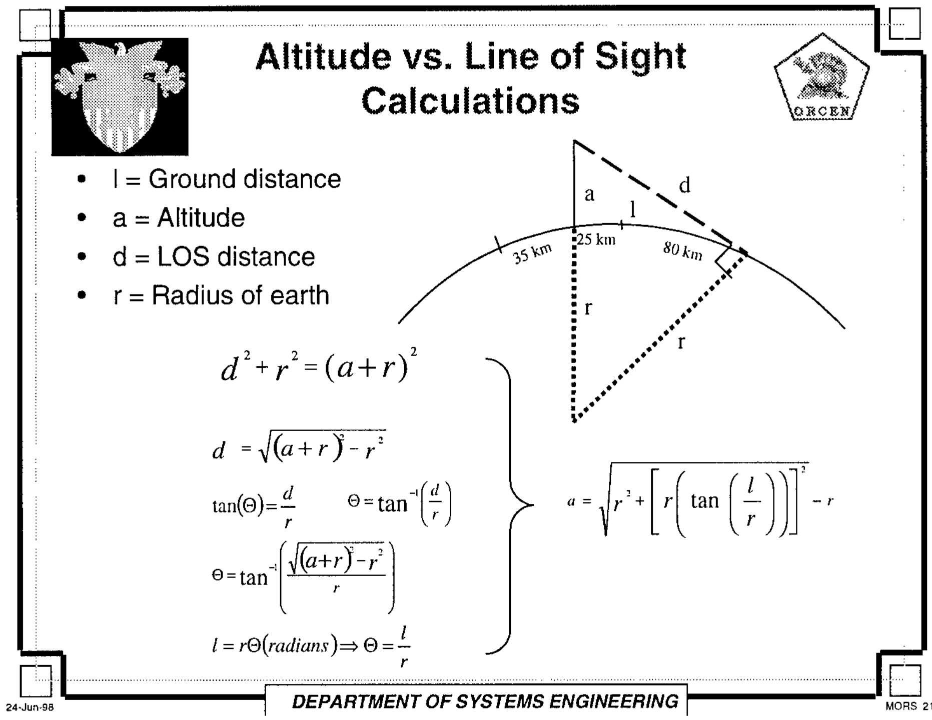
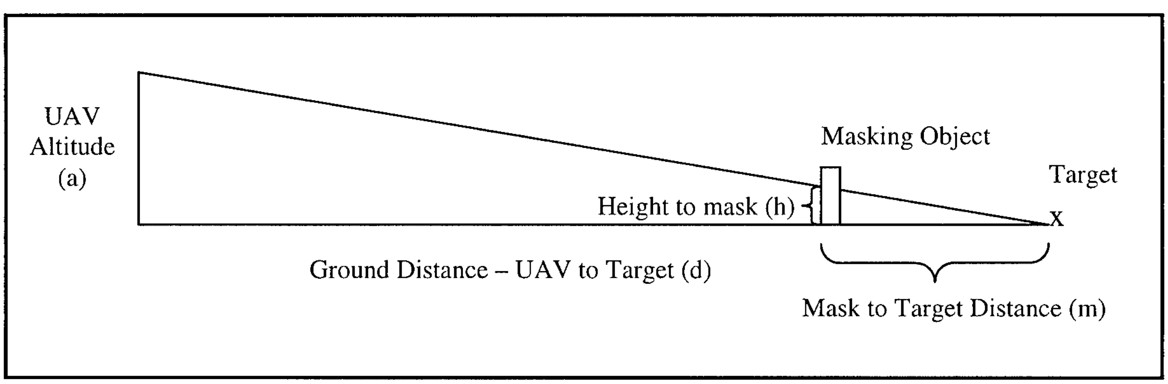


Figure 5: Altitude vs. Line of Sight

The following calculations demonstrate the masking effect of terrain or other obstacles on a UAV's ability to acquire distant targets. A "flat earth" is assumed, since the distances are less than 50 Km and the actual contour of the ground between the UAV and the target could vary significantly. The target is assumed to be 1 meter in height.



Calculations:

The height of an object which will mask the target is given by:

$$h = m\left(\frac{a}{d}\right)$$

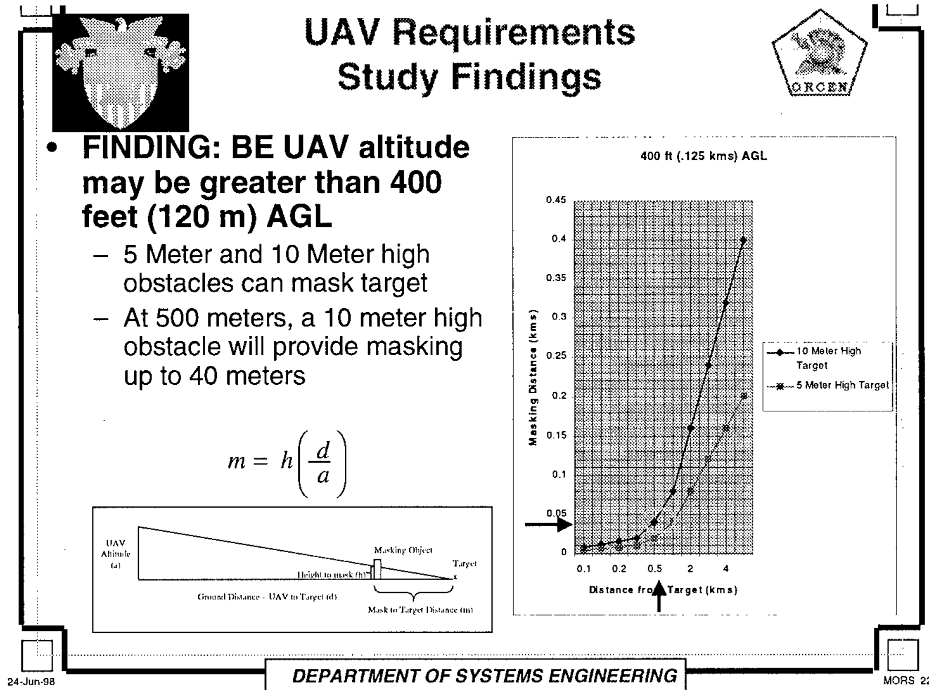


Figure 6: 500 m (AGL) Line of Sight

Sample calculations for UAV altitudes of 500, 2000 and 5000 meters are as follows:

Masking Object to Target: 5 meters

UAV to Target - Ground Distance (Km)	Mask Height - UAV at 500 Meters (m)	Mask Height - UAV at 2000 Meters (m)	Mask Height - UAV at 5000 Meters (m)
2	2.25	6.00	13.50
4	1.63	3.50	7.25
6	1.42	2.67	5.17
8	1.31	2.25	4.13
10	1.25	2.00	3.50
12	1.21	1.83	3.08
14	1.18	1.71	2.79
16	1.16	1.63	2.56
18	1.14	1.56	2.39
20	1.13	1.50	2.25
22	1.11	1.45	2.14
24	1.10	1.42	2.04
26	1.10	1.38	1.96
28	1.09	1.36	1.89
30	1.08	1.33	1.83
32	1.08	1.31	1.78
34	1.07	1.29	1.74
36	1.07	1.28	1.69
38	1.07	1.26	1.66
40	1.06	1.25	1.63
42	1.06	1.24	1.60
44	1.06	1.23	1.57
46	1.05	1.22	1.54
48	1.05	1.21	1.52

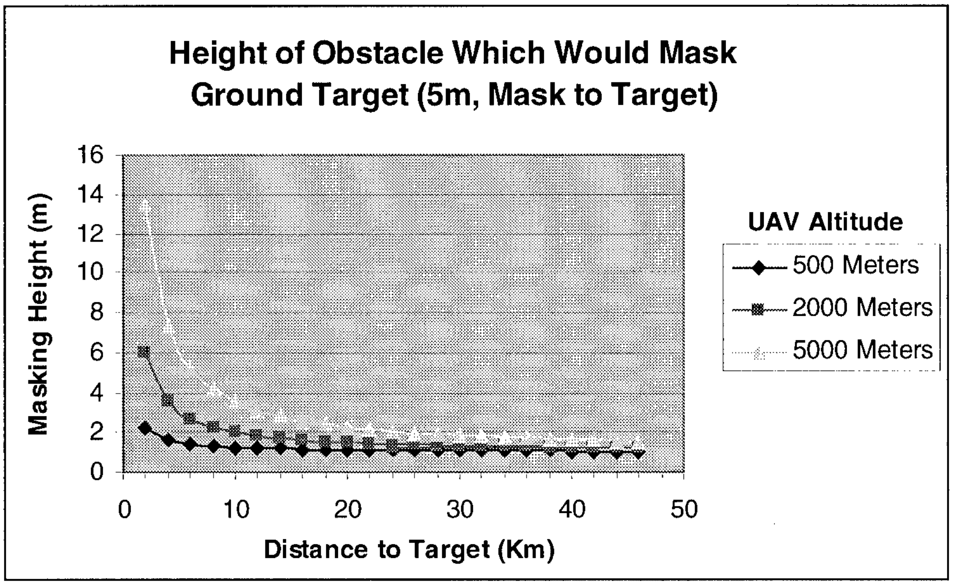
Masking Object to Target: 25 meters

UAV to Target - Ground Distance (Km)	Mask Height - UAV at 500 Meters (m)	Mask Height - UAV at 2000 Meters (m)	Mask Height - UAV at 5000 Meters (m)
2	7.25	26.00	63.50
4	4.13	13.50	32.25
6	3.08	9.33	21.83
8	2.56	7.25	16.63
10	2.25	6.00	13.50
12	2.04	5.17	11.42
14	1.89	4.57	9.93
16	1.78	4.13	8.81
18	1.69	3.78	7.94
20	1.63	3.50	7.25
22	1.57	3.27	6.68
24	1.52	3.08	6.21
26	1.48	2.92	5.81
28	1.45	2.79	5.46
30	1.42	2.67	5.17
32	1.39	2.56	4.91
34	1.37	2.47	4.68
36	1.35	2.39	4.47
38	1.33	2.32	4.29
40	1.31	2.25	4.13
42	1.30	2.19	3.98
44	1.28	2.14	3.84
46	1.27	2.09	3.72
48	1.26	2.04	3.60

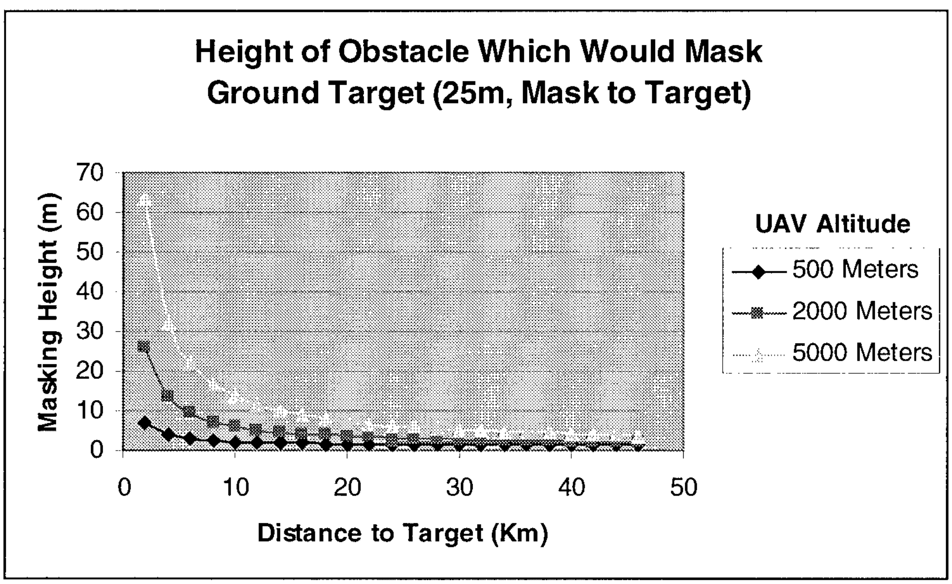
Masking Object to Target: 100 meters

UAV to Target - Ground Distance (Km)	Mask Height - UAV at 500 Meters (m)	Mask Height - UAV at 2000 Meters (m)	Mask Height - UAV at 5000 Meters (m)
2	26.00	101.00	251.00
4	13.50	51.00	126.00
6	9.33	34.33	84.33
8	7.25	26.00	63.50
10	6.00	21.00	51.00
12	5.17	17.67	42.67
14	4.57	15.29	36.71
16	4.13	13.50	32.25
18	3.78	12.11	28.78
20	3.50	11.00	26.00
22	3.27	10.09	23.73
24	3.08	9.33	21.83
26	2.92	8.69	20.23
28	2.79	8.14	18.86
30	2.67	7.67	17.67
32	2.56	7.25	16.63
34	2.47	6.88	15.71
36	2.39	6.56	14.89
38	2.32	6.26	14.16
40	2.25	6.00	13.50
42	2.19	5.76	12.90
44	2.14	5.55	12.36
46	2.09	5.35	11.87
48	2.04	5.17	11.42

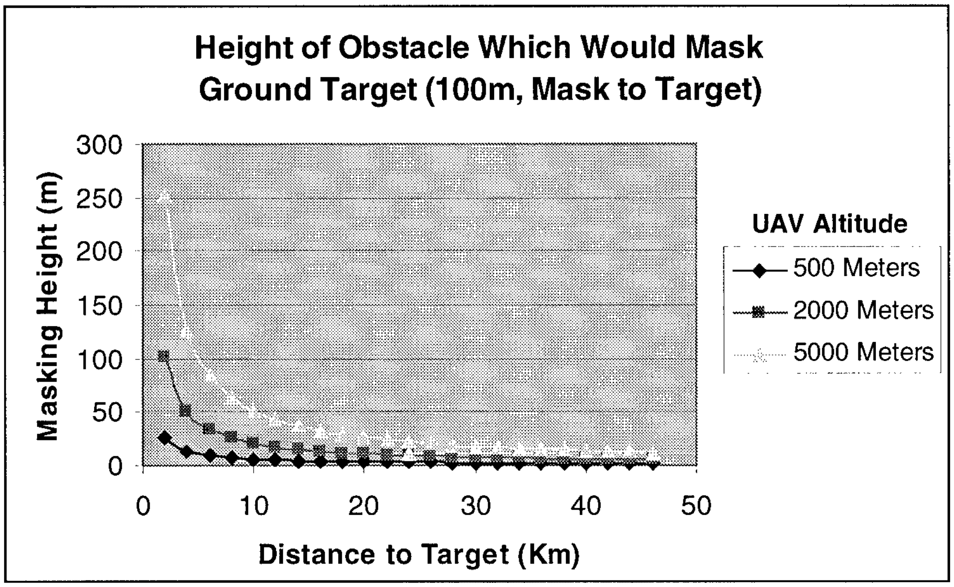
Graphically summarizing these results allows us to see the trade-offs between UAV altitude and potential target masking:



This shows that a target can easily be hidden from the UAV's field of view if it is located very close to a masking feature (buildings, tree line, etc.). The altitude of the UAV matters little if the target is more than approximately 5-10 kilometers away.



When the distance between the masking object and the target increases to 25 meters, the altitude of the UAV becomes more important. Higher flying UAVs may be able to detect targets behind a 10 meter object out to about 15 kilometers. Lower flying UAV are still obstructed by small obstacles at even short distances.



When the distance between the masking object and the target is increased to 100 meters, the altitude of the UAV becomes very important: at 30 kilometers, it would take an object less than 3 meters high to mask the target from a UAV flying at 500 meters, while the object would have to be almost 18 meters high to mask the target from a UAV flying at 5000 meters.

Appendix F: Number of Trials Required

To calculate the sample size n required for a given margin of error m, we use:

$$n = \left(\frac{z^* \sigma}{m} \right)^2$$

where z* is the critical value for the desired level of confidence and σ is the standard deviation of the initial test trials[23].

In this case, if we want to be 95% certain we've captured the true mean, we use a z* of 1.960. The standard deviation of the initial ten runs was 21.74. Therefore, if we specify a margin of error of ±4 Red kills, we get:

$$n = \left(\frac{1.96 * 21.74}{4} \right)^2 = 110.68$$

Therefore we would have to conduct 111 independent trials.

[23] Moore and McCabe, Introduction to the Practice of Statistics, p. 438.

Appendix G: Size of Deadly Zone

Calculations for estimating size of Deadly Zone*

LINEAR REGRESSION MODEL	
kph	Deadly zone (km)
2.5	1
20	15
30	250
40	271.4247312
60	433.8763441
100	758.7795699
200	1571.037634
300	2383.295699
400	3195.553763

← **Current Ground Speed** →

EXPONENTIAL MODEL	
kph	Deadly Zone (km)
2.5	0.826484878
20	25.33349965
30	179.1022581
40	1266.213484
60	63287.60762
100	158103749.3
200	4.93175E+16
300	1.53837E+25
400	4.79864E+33

Y = -53.48 * 8.123X

Y = 0.05069 * EXP(0.1956*X)

Limited Data points

Linear regression:

- Not strongly correlated
- Lower bound?

Exponential Regression:

- Strongly Correlation
- Unrealistic results?

* MG Scales, *Cycles of War*, *AFI Journal JUL 97*

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Figure 7: Size of Deadly Zone

Appendix H:

Appendix I: Other

Appendix J: References (ALL)

Moore and McCabe, Introduction to the Practice of Statistics, W.H. Freeman and Company, NY, 1993.
Knowledge and Speed
Army After Next Project: Emerging Impressions
AAN Concepts: Future Air Mechanized Operations
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Exploring Tactical and Operational Concepts in Support of Army After Next
AAN Battle Command
CRC Standard Mathematical Tables 25th Edition
Probability and Statistics for Engineers and the Sciences, Third Edition
HP 48G User's Guide
Excel 97

1 Knowledge and Speed: The Annual Report on The Army After Next Project to the Chief of Staff of the Army Knowledge and Speed, JUL 97, pg 20
2 Knowledge and Speed: The Annual Report on The Army After Next Project to the Chief of Staff of the Army Knowledge and Speed, JUL 97, pg 13
3 Ibid.
4 Made by Analyst
5 Ibid.
6 Ibid.
7 The Army After Next Battle Force, Army After Next Tactical Workbook, 2 JAN 97 pg 16
8 Knowledge and Speed: The Annual Report on The Army After Next Project to the Chief of Staff of the Army Knowledge and Speed, JUL 97, pg 9
9 IPR with COL Kirin, 23 OCT 97
10 TRAC Briefing: Exploring Tactical and Operational Concepts in Support of Army After Next slide 22.
11 Appendix A contains a copy of the survey.
12 For complete survey results, see Appendix B.
13 MG Scales Cycles Of War, Armed Force Journal International, July 1997
14 The Army After Next Battle Force, Army After Next Tactical Workbook, 2 JAN 97 pg 16
15 Sage, Andrew P., Systems Engineering, John P. Wiley and Sons, 1992 p.60
16 EADSIM is produced by Teledyne-Brown Engineering under contract by the U.S. Army Space and Missile Defense Command (SMDC), Attn: CSSD-BC-T, P.O. Box 1500, Huntsville, AL 35807
17 Data files we provided by Ms. Pam Caruso, from the Space and Missile Defense Battle Lab.
18 The scenario details are several hundred pages long and can be found at http://www.orcen.usma.edu/papers/fy98/aan/.
19 Details of the analysis are at Appendix C.
20 Details are at Appendix D.
21 For sample calculations, see Appendix E.
22 See Appendix F for calculations.
23 Moore and McCabe, Introduction to the Practice of Statistics, p. 438.